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SOME PROBLEMS OF THE NATIONAL BUREAU OF STANDARDS.*

BY

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The advantages of a uniform system of weights and measures for the whole nation are so obvious in our present-day development of commerce and industry that we seldom stop to consider how uniformity was brought about or the difficulties involved in maintaining it. I wish to invite your attention to certain features of this evolutionary process, in the course of which our standards have become more precisely defined and established.

Presumably the difficulties under which commerce had been carried out among the thirteen Colonies, owing to the lack of uniform standards, were responsible in part for that wise and far-sighted provision of the Constitution which delegated to Congress the authority "to fix the standards of weights and measures." It is remarkable that under such circumstances Congress did not take prompt steps to correct the situation. In the early days of the new Republic, Washington in his presidential messages to Congress repeatedly urged the importance of carrying out this constitutional provision; but for eighty years no formal action was taken by Congress to "fix" the standards, save for the adoption in 1828 of a standard Troy pound for coinage purposes.

* Presented at a meeting held Thursday, March 26, 1936.

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Not that the subject was ignored. Repeatedly the matter came up for discussion, without definite action. A standard of length which could if necessary be independently reproduced from physical observations repeatedly intrigued the interest of Congress. Jefferson, as Secretary of State, presented in 1790 an elaborate report on weights and measures, including the proposal of a standard of length based upon the length of a uniform cylindrical pendulum beating seconds at sea-level at 45° N. Lat. In 1795, President Washington presented to Congress a communication from the Minister of the French Republic suggesting the adoption by the United States of the metric system of weights and measures which France had adopted four years earlier. This proposal, however, met with little favor. A standard based on the length of one ten-millionth of the earth's quadrant apparently had less appeal from the standpoint of reproducibility than one based on the length of a pendulum beating seconds.

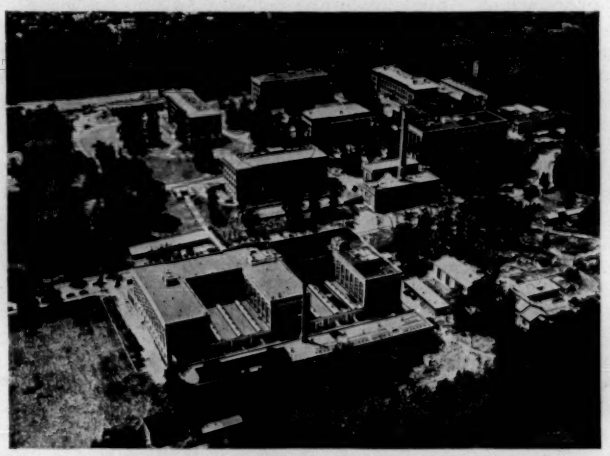
Meanwhile, various State legislatures were imploring Congress to take some action to bring about uniformity; and in 1821, John Quincy Adams, as Secretary of State, urged Congress "to fix the standard with the partial uniformity of which it is susceptible at present, excluding all innovations. To consult with foreign nations for the future and ultimate establishment of universal and permanent uniformity."

In 1830 the Treasury Department, which was charged with the collection of customs, was instructed through a resolution of the Senate to investigate the weights and measures in use in the various customs houses of the country, with a view to bringing about uniformity in the collection of customs. The Secretary of the Treasury gave a broad interpretation to this authority to "investigate" and the outcome was the adoption by the Treasury Department, without further action by Congress, of an avoirdupois pound of 7,000 grains, a yard of 36 inches, a wine gallon of 231 cubic inches, and a Winchester bushel of 2,150.42 cubic inches, for use in the collection of customs.

So well pleased was Congress with this solution of its difficulties that the Secretary of the Treasury in 1836 was directed through a joint resolution to deliver to the Governor of each State a complete set of all the weights and measures

adopted as standard by the Treasury Department. Although no Congressional action was taken to legalize these standards, many of the States adopted them independently, and a ground work for uniform weights and measures was at last provided.[1]

It was not until after the Civil War that Congress took the first formal steps to legalize a system of weights and



AIRPLANE VIEW OF THE NATIONAL BUREAU OF STANDARDS

The laboratories are housed in over a dozen permanent buildings on a site of 56 acres in the northwest section of Washington, about 4 miles from the center of the city.

measures, and this oddly enough did not refer to the weights and measures in common use, but the metric system, rejected in 1795. The act of 1866 reads as follows: "It shall be lawful throughout the United States of America to employ the weights and measures of the metric system; and no contract or dealing or pleading in any court shall be deemed invalid, or liable to objection, because the weights or measures

[1] Those who may desire to pursue the subject further are referred to an interesting summary by Miss Sarah Ann Jones, entitled "Weights and Measures in Congress." Miscellaneous publication, M 122, National Bureau of Standards, 1936.

expressed or referred to therein are weights or measures of the metric system."

We thus have the anomalous situation in this country of a legalized system of metric weights and measures which is not in common use, and a customary system of weights and measures which has never been formally legalized. However, in the Act of 1866 Congress did include a table of conversion factors which "may lawfully be used" in going from one system to the other. That Congress intended this table only as an approximation to the true ratio of the units in the two systems is evident from the fact that the meter is given as equivalent to 39.37 inches, while the millimeter is rounded off to .0394 inch.

The platinum-iridium meter and kilogram, supplied to our Government as a result of its participation in the Metric Convention, provided this country with far better material standards than it had ever had before. Both the meter-bar and the kilogram had been carefully compared with the international prototypes, and the coefficient of expansion of the meter-bar had been measured. Moreover, they constituted, together with the Troy pound, the only legal material standards possessed by the Government. Accordingly, in the absence of further Congressional action, Superintendent Mendenhall of the Coast and Geodetic Survey in 1893 issued the following order: "The Office of Weights and Measures with the approval of the Secretary of the Treasury, will in the future regard the international prototype meter and kilogram as fundamental standards, and the customary units, the yard and the pound, will be derived therefrom in accordance with the act of July 28, 1866." To pass from the meter to the inch the Office of Weights and Measures adopted the conversion factor one meter equals 39.37 inches, as set up in the Act of 1866; and this ratio has been adhered to since that time.

The British inch, derived directly from the Imperial yard, is about four parts in a million shorter than the United States unit. The conversion factor, one inch equals 25.4 millimeters exactly, falls midway between the present accepted values of the British and the United States inch. The National Bureau of Standards has suggested this value as a

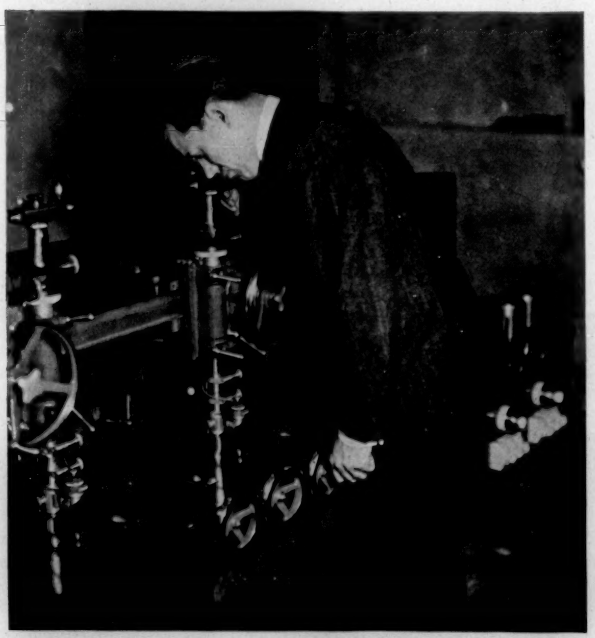
basis for international uniformity. Both countries could accept the change of two parts in a million in the magnitude of the inch without doing violence to the standards of either, and in this way bring the value of their length standards into accord. The change would not affect industry in the slightest because it falls far within the tolerances employed in industrial measurements. (A change of only 1° C. in the temperature of a steel gage-block changes its length by 10 parts in a million—five times the proposed change in the unit itself.) The new value would need to be considered only in the most precise measurements, such as the calibration of high-precision standard gage-blocks. As a matter of fact, the conversion factor, one inch equals 25.4 millimeters, has recently been adopted for industrial purposes by standardizing groups in fifteen countries, including the United States and Great Britain. I am hopeful that both England and the United States will soon formally adopt this conversion factor, thus settling the question.

It may appear to you that this matter might easily have been settled long ago. We must remember however that the Imperial yard has long been the British standard of length, and that the traditional conservative Briton is slow to approve innovations in such matters. Until recently there was also in the United States outspoken opposition to defining the inch in terms of the meter, which I believe was engendered in part by the feeling that this was but an opening wedge in a movement to substitute metric measures for the customary measures in the United States. This feeling I think has now largely disappeared. The approval of the 25.4 conversion factor by the American Standards Association did much to clear the air.

When a uniform relation between the meter and the inch is formally adopted it should be accompanied by an official definition of the number of wave-lengths of red radiation from cadmium in the meter. The International Committee of Weights and Measures has provisionally adopted the value, determined by Benoit, Fabry and Perot, for the wave-length of red radiation of cadmium in relation to the meter. The Committee is reluctant to take the further step of defining the meter as equal to a given number of light-waves because

to date meter-bars have not been derived directly from light-waves with the precision attainable in meter-bar comparisons.

For the calibration and production of end standards up to one decimeter in length, however, the light waves have been employed with greater accuracy than can be attained in line-standard calibration. The application of the light waves to greater lengths awaits future developments. The constancy of light wave-lengths is indicated by a great mass



USING THE HIGH PRECISION LONGITUDINAL COMPARATOR

By means of this instrument the national standard of length, maintained by the National Bureau of Standards, is put into actual use in commerce and industry. Working standards of length are compared with the national standard, and against these, in turn, are checked the standards of manufacturers and commercial laboratories.

of spectroscopic data. The known tendency of some material length-standards to change with time emphasizes the value of direct measurements in terms of wave-lengths of light as an aid in maintaining precise length-standards.

ELECTRICAL UNITS AND STANDARDS.

The field of electricity affords an outstanding example of general dependence upon national standardizing laboratories for the tools of measurement. No one outside of such laboratories now expects to establish his own standards. This was not true a generation ago, and the change in practice has had a notable effect upon the choice of fundamental standards and upon the definitions of the units themselves.

In the choice of units and standards consideration must be given to two desirable characteristics. These are, first, uniformity of values, and second, logical relations to units and standards of other kinds. In some cases both of these can not readily be attained.

If measurements are to be most useful, it is obvious that they must have a common basis. That is, uniformity of values is essential. It is also desirable that units in electricity, for example, be based upon principles which give them a definite relation to units of other kinds, such as those of mechanics. Our present system of electrical units was established as a compromise between these two desirable characteristics.

The present electrical units were intended to be concordant with mechanical units as closely as the values could be determined at the time, but when they were established the need for uniformity overshadowed the desirability of concordance between the two systems. The practical attainment of uniformity among different laboratories seemed to require that the electrical units be independently defined in terms of standards which could be set up in any laboratory. So the ohm was defined as the resistance of a specified column of mercury, the ampere as the current which will deposit silver at a certain rate from a silver nitrate solution under specified conditions, and other units were derived from these two.

In actual practice, however, the system has not worked

out quite as was expected. In the first place, while the primary standards chosen would easily reproduce values to a few parts in 10,000, their improvement so as to reduce the uncertainty to a few parts in 100,000 proved to be very difficult. In the second place, standard cells and wire resistance coils were greatly improved so that values of units could be maintained over long periods of time with such certainty that parts in 1,000,000 became significant.

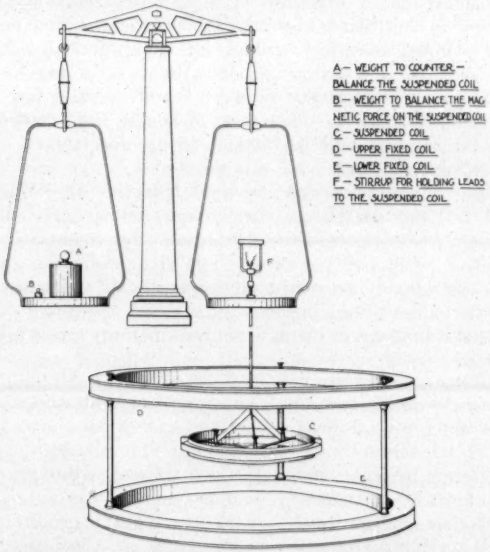
Simultaneously with this development of dependable reference standards came the rise of the great national standardizing laboratories, especially in Germany, Great Britain, and the United States, and of other laboratories more or less comparable in several other countries. The result of this centralization of responsibility for maintenance of units has been that both uniformity and correctness of principle are made attainable on a world-wide basis through the collaboration of these laboratories with one another and the dissemination of calibrated standards by them in their respective domains. The revision of the electrical units which has thus been made practicable is under way at the present time.

The legal mechanism for international collaboration in problems of measurement is the International Committee on Weights and Measures. This Committee was established before the national laboratories were created, and the laboratories have no direct part in the operation of the Committee. However, when jurisdiction over electrical units was given to the International Committee in 1927, the national laboratories were brought into the scheme of organization through the formation of an international Advisory Committee on Electricity, on which six of the national laboratories are represented.

When this new organization for work on electrical units was set up, the first step taken by the National Bureau of Standards was the formation of an American Advisory Committee, including representatives of all national organizations in this country interested in precise electrical measurements. This American Committee recommended that the practical electrical units be revised to make them concordant with the fundamental centimeter-gram-second system of units.

The recommendations of the American Committee were so

ably presented by Dr. George K. Burgess, then Director of the Bureau of Standards, that they were unanimously adopted at the first meeting of the International Advisory Committee in 1928. In order to carry them into effect it was necessary to make new absolute determinations of the values of the units. A program of such determinations was begun in five of the national laboratories, and it was expected that the new


A— WEIGHT TO COUNTER-BALANCE THE SUSPENDED COIL
B— WEIGHT TO BALANCE THE MAGNETIC FORCE ON THE SUSPENDED COIL
C— SUSPENDED COIL
D— UPPER FIXED COIL
E— LOWER FIXED COIL
F— STIRRUP FOR HOLDING LEADS TO THE SUSPENDED COIL

DIAGRAMMATIC VIEW SHOWING PRINCIPLE OF THE CURRENT BALANCE

An electric current flowing through the coils *C*, *D*, and *E* is measured by weights balancing the electromotive force exerted on *C*. In this way a direct relationship is established between one of the electrical units, the ampere, and the mechanical unit of force.

values of the units could be established in 1935. In all the laboratories, however, it has been difficult to support such work during the past few years. The National Bureau of Standards is the only one which has yet published its results.

At the 1935 meeting of the International Committee it was decided to set January 1, 1940, as the date for intro-

duction of the new values into actual use. In the meantime, comparisons must be made between the results of determinations in various laboratories, and agreement reached upon the values which are best in the light of the combined results. It is hoped that the absolute values can be established with an uncertainty of only a very few parts in 100,000. Measurements already made on standard resistance coils and standard cells show that a precision of a part in 1,000,000 can be attained in comparisons between laboratories. Consequently, it is planned to assign values for the practical reference standards to this precision. In other words, in electrical measurements uniformity between countries to a few parts in 1,000,000 may be expected, although the relations to mechanical units will be subject to an uncertainty of ten times that magnitude.

The change which is to be made effective on January 1, 1940, will not trouble any one except laboratories making precise measurements, since the largest adjustment necessary will be 1/20 of one per cent. The changes in the various units can already be predicted to the fourth decimal place, and the values of our present units, which are called "international," in terms of the new or absolute units are as follows:

1 Ampere International	= 0.999 9 Ampere Absolute.
1 Coulomb International	= 0.999 9 Coulomb Absolute.
1 Ohm International	= 1.000 5 Ohm Absolute.
1 Volt International	= 1.000 4 Volt Absolute.
1 Henry International	= 1.000 5 Henry Absolute.
1 Farad International	= 0.999 5 Farad Absolute.
1 Weber International	= 1.000 4 Weber Absolute.
1 Watt International	= 1.000 3 Watt Absolute.
1 Joule International	= 1.000 3 Joule Absolute.

PHOTOMETRIC UNITS AND STANDARDS.

In photometry, international uniformity has never been reached, but that end now appears to be attainable within a reasonable time.

Some of you may recall that in 1909 a unit called the "International Candle" was adopted by agreement between France, Great Britain, and the United States. In fact,

Philadelphians had an important part in that accomplishment through the interest of the old American Gas Institute, predecessor of the American Gas Association. The adjustment made at that time in American units of candlepower served the double purpose of reconciling the difference which had existed between the units of the gas and the electrical industries, and of bringing the new American unit into agreement with the British and French.

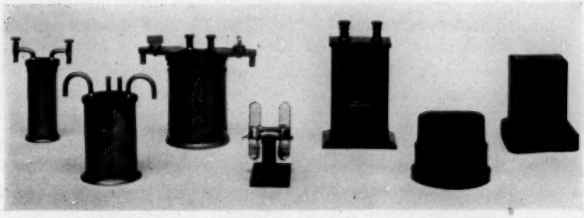
The "International Candle" thus established has since been accepted by the International Commission on Illumination and has come into use in nearly all countries. In three important respects, however, the agreement of 1909 was incomplete. First, the German-speaking countries never accepted it, but continued to use their own unit, the Hefner candle, which has about 0.9 the magnitude of the "International" unit. Second, no provision was made for a fundamental standard, and each country continued to maintain its unit in its own way. Third and most important in practice, the old units were all represented by flame standards or carbon-filament lamps giving light of a yellowish color, and no agreement was reached regarding the methods of passing over to lamps giving "whiter" light. Consequently, when the modern tungsten-filament lamps were developed they were rated in more or less diverse ways in different countries; difficulties of this kind have of course been still more accentuated with the invention of the many newer lamps giving light of a wide diversity of color.

In photometry, as in electricity and other fields of measurement, it has been considered the duty of the National Bureau of Standards to seek international uniformity of units, standards, and methods of measurement, in so far as that can be done without detriment to our own national interests. This has been done in photometry through participation in the work of the International Commission on Illumination and, more recently, the official International Committee on Weights and Measures. The latter body has created an Advisory Committee on Photometry, of which the Bureau is a member along with five other national laboratories.

Through these international organizations considerable progress has been made toward agreement upon a uniform

photometric scale or system of units. It may properly be said that a large part of this progress is based directly upon experimental work done in the laboratories of the Bureau.

In particular, the Bureau's determinations of the behavior of the average, or "normal," eye have been internationally accepted in the form of "factors of visibility" (better called factors of luminosity). These give a basis for measuring lights of any color if one has a standard of some kind as a starting point. The Bureau has also shown that the complete radiator or "black body" at the temperature fixed by the freezing of pure platinum is a practicable and precise primary standard. This idea also has been internationally accepted.



STANDARDS USED IN THE MAINTENANCE OF THE ELECTRICAL UNITS

Resistance coils and standard cells of the types shown constitute the basis of all precise electrical measurement. In the center is a Weston normal cell of the type used by the Bureau and other national standardizing laboratories to maintain the volt. At the right are three portable standard cells as supplied commercially.

The only additional step needed in order to provide a complete framework of principles for the photometric scale is to agree upon a numerical value for the brightness of the primary standard.

On this point, it had been expected that the value for the primary standard would be so chosen as to preserve the old "International Candle" as represented by carbon-filament lamps. In terms of this unit, the primary standard has a brightness of about 58.9 candles per square centimeter. Keeping this unit, however, would involve two difficulties. First, the step-up from the yellower sources to modern tungsten lamps in accordance with the visibility factors would give ratings for the common types of tungsten lamps somewhat below those now in effect, thus disturbing present

commercial practice in order to preserve a historical unit; and, second, there would still be two systems of units because Germany will not accept the International Candle.

In the hope of clearing up all these difficulties at once the Bureau has recently suggested that the old International candle be abandoned and that a slightly different unit be fixed by taking the round value of 60 candles per square centimeter, instead of 58.9, as the brightness of the black-body radiator at the platinum point. The French and German national laboratories have agreed to this plan, provided that other countries using the International candle also agree. The question is now before the national laboratory of Great Britain. It is hoped that the four laboratories, which have the responsibility for establishing and maintaining the two present photometric units, can join in a formal proposal to the International Committee on Weights and Measures to substitute for them a single new system of units which would then undoubtedly be accepted throughout the world.

TESTING.

The problems which we have just been discussing illustrate a basic part of the Bureau's work. The greatest single activity of the Bureau, however, is to be found in the field of testing. One important phase of this work is the determination of the corrections which must be applied to the working standards of the research laboratory and the factory to make them conform with the national standards. This is the most direct and effective way of promoting the use of correct and uniform standards in science and industry.

Through a wise provision in the Organic Act establishing the Bureau, this testing service is free to Government agencies and to State universities and other State institutions. To others a fee covering the actual cost of the work is charged, but these fees are returned to the Treasury as miscellaneous receipts and are not available to support the Bureau's work. So the more business we do, the poorer we are. The problem in this case is to maintain a staff large enough to give the prompt service which the research agencies almost invariably request.

The purchasing of Government supplies on the basis of

specifications with free competitive bidding is now well recognized as necessary and advantageous. To insure the success of this procedure, two principles must be rigorously observed: (1) Adequate specifications must be developed setting forth clearly the desired properties of the commodity—properties which must be capable of quantitative measurement; (2) the delivered supplies must be tested to determine whether they meet the requirements of the specification.

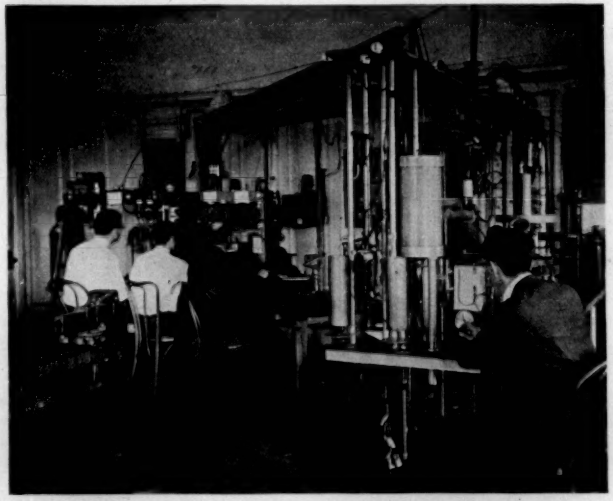
Through the coöperation of technical men from all branches of the Government, including a large number from the Bureau's staff, over 1,000 specifications have been prepared under the supervision of the Federal Specifications Executive Committee, of which the Director of the Bureau of Standards is chairman. It is essential that these specifications shall provide supplies which are satisfactory in service, and to this end they are constantly being revised and strengthened in the light of information gained in the laboratories of the Bureau and other Government agencies.

The testing of Government supplies to determine whether they meet the requirements of the specifications is an equally important service. In this work the testing facilities of the National Bureau of Standards are being utilized more and more each year by other Government agencies. The testing of 4,400,000 barrels of cement during the year for use in numerous construction projects of the Government and of approximately 110,000 clinical thermometers, largely for the United States Veterans' Bureau, are examples.

A recent delivery on a Government order for 15,000 pounds of white lead for use as paint was found to contain no lead at all, and another delivery on an order for 5,000 pounds of zinc oxide contained no zinc oxide. Such cases illustrate the necessity of testing. No matter how excellent the purchase specification may be, it is fruitless without adequate tests to prove that the delivered material meets its requirements.

The demand upon the Bureau for technical information, exclusive of testing, has increased so rapidly in recent years as to necessitate its recognition as an important service function, requiring about 14 per cent. of the time of our technical staff. Government agencies, State and municipal officials, industrial firms, and citizens the country over, look to the

Bureau as a source of up-to-date information on technical matters within its field. In cases of special importance where necessary information is not available, a laboratory study is made, such as the recent investigation carried out at the request of the cities of Dallas and Fort Worth, to determine



APPARATUS USED IN DETERMINING THE PROPERTIES OF SATURATED STEAM

This view shows the calorimetric equipment and recording apparatus as used during research on the properties of steam in the range from 212° F. (15 lb./in.²) to 705° F. (3,200 lb./in.²).

whether the dilution of west Texas natural gas with inert gases is advantageous to the customers, as claimed by the gas company.

APPLIED RESEARCH.

The testing and information service of the Bureau, the development of safety codes and building codes, the establishment of trade standards and specifications all must rest for their success upon a firm foundation of fact. These facts often can only be established by laboratory measurements. Research thus becomes a vitally important part of the

Bureau's work, not only in these features, but in the basic functions involved in the development and maintenance of the Nation's standards of weights and measures. Its encouragement and support are not only essential for the development of new and better ways of doing useful things, but it constitutes in fact the very foundation of further advancement.

Most of the research carried out at the Bureau at the present time is necessarily planned with reference to the solution of some specific problem. This need not be deplored. The research man who can contribute to the solution of an industrial problem is not only advancing our knowledge in that particular field, but he has the added satisfaction of seeing his work applied and utilized. From an administrative standpoint it is less difficult to secure funds for a practical project than for one involving abstract, basic research. Of the urgent need for the latter I shall have something to say later.

A problem with a practical application is not necessarily one that is less fundamental in character. As a matter of fact the solution of a problem from the standpoint of its practical applications cannot be considered as complete until these fundamental relations have been established. The point is illustrated by the use of the spectroscope for the quantitative determination of minute amounts of certain metals in the presence of others. In this work an important criterion is the intensity of a certain spectral line in each element known as the "raie ultime," which is the last line to disappear as the amount of the element being studied is made vanishingly small. Dr. Meggers of our staff has found that this persistent spectral line ("raie ultime") is associated with a change in the energy level of the atom when a single electron changes its azimuthal quantum number from 0 to 1. Now from the modern atomic theory it is possible to determine qualitatively for each element in what part of the spectrum a spectral line with this characteristic would occur. From this we can decide which elements have a "raie ultime" which falls within the working limits of the spectrum, and consequently which elements can be minutely determined by spectroscopic analysis and which cannot. The development of this fundamental relationship thus contributes greatly both

to the practical use of spectroscopic analysis and also in establishing the limitations of the method, a matter of prime importance in all analytical work.

Time permits only the mention of a few problems in applied research that are now being studied at the Bureau.

A most thorough investigation is being made of the thermodynamic properties of saturated steam at various temperatures

DETERMINATION OF STRESS DISTRIBUTION IN RIGID FRAMES

This is a coöperative project with the American Institute of Steel Construction. The frame shown in the picture was submitted by the American Bridge Company. It has been mounted in the 600,000-pound testing machine and strain gage readings are being obtained with a Whittemore strain gage.

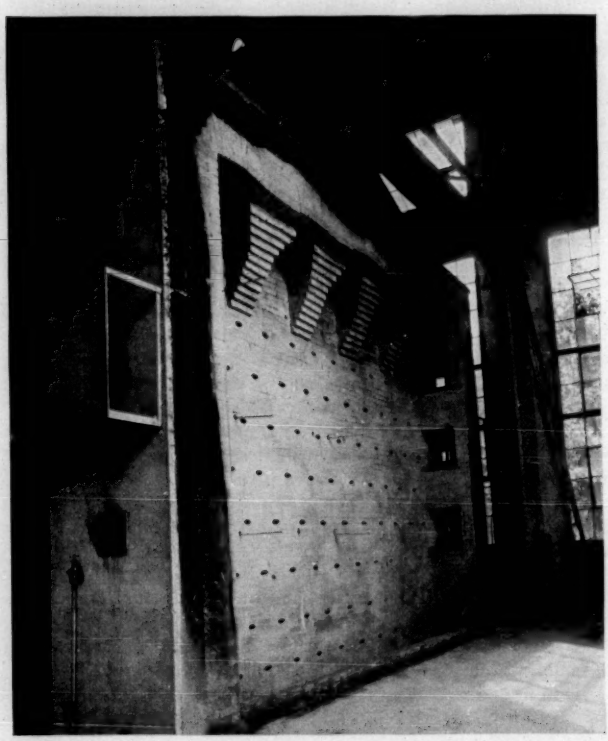
and pressures up to the critical point. This is being carried out in collaboration with other groups in this country and abroad as a basis for the preparation of an international steam table. The next step is the extension of the work into the realm of superheated steam. The Bureau has been urgently requested to undertake this as a necessary basis for the most effective development of the modern steam turbine.

Airplane propellers occasionally break in the air. The resulting unbalance sometimes tears the engine from the airplane. Examination of the fractures clearly shows them to be fatigue failures, brought about by vibration either of the blades alone or of the crankshaft and blades together. Typical failures have been produced at the Bureau by vibrating a propeller blade at its fundamental critical frequency. How can these disastrous failures be eliminated? Laborious inspection at frequent intervals to determine whether fatigue cracks have started to develop is the procedure now being used. The fundamental problem has not been solved.

Enormous losses, conservatively estimated at $100,000,000 annually, result from the corrosion of buried pipe-lines carrying gas, oil or water. Studies made by the Bureau in cooperation with the American Petroleum Institute and the American Gas Association show that the rate of corrosion, which results from electrolytic reaction of the moist soil with the pipe, varies greatly with the character of the soil. No metallic pipe seems to be completely immune to this attack in all soils. The development of effective protective coatings which can be applied at a reasonable cost is an outstanding economic problem.

Studies are being made of the fire-resistance of different types of structures. Slow-burning construction is a great advantage in homes and other buildings where fire-proof construction is not feasible, because it provides time to fight the fire. Slow-burning partitions are now under investigation at the Bureau, in relation to their use in homes and in passenger ships. The fire loss of this country amounts to $450,000,000 a year. I wonder if you visualize what this means. It is equivalent to the annual destruction of a row of $10,000 homes on 100-foot lots lining one side of a highway extending from here (Philadelphia) to Chicago. And if you rode the length

of this highway of holocaust, you would find in front of the ruins of one home in every five a white cross telling its mute story of the loss of a life from fire. If painstaking laboratory fire-tests point the way to the reduction of this appalling loss



FURNACE FOR FIRE TESTS OF WALLS, PARTITIONS, THEATRE PROSCENIUM CURTAINS, AND FIRE-RESISTANT BULKHEADS FOR SHIPS

The construction to be tested is placed to form one wall of the furnace chamber. By means of gas burners, the outlets of which are seen in the photograph, temperatures are built up within the furnace according to a predetermined schedule. The temperatures developed on the side of the wall not exposed to fire are noted, and the deflection and stability of the construction under the conditions of the test are determined.

of life and property, is any undertaking more worthy of support?

The world hears little about the bridges that do not fail or the ships that are not lost at sea or the skyscrapers that do not fall down. The painstaking research that made them possible is taken for granted. This is not news. But when bridges and ships and airplanes and dirigibles are made bigger and bigger without simultaneously making them better and better, then comes news, stark news—a failure, a tragedy and an investigation. When shall we learn that engineering research must not only keep abreast but ahead of engineering development if these failures, these tragedies, are to be avoided? When shall we learn that engineering research should be generously supported because it pays—pays richly in things that do not happen?

BASIC RESEARCH.

Finally, I present a subject that in my judgment is of outstanding economic importance to the nation; namely, the adequate and generous support of basic research in physics and chemistry, as a foundation for the further development of industry and commerce in the United States.

The Federal government is now appropriating over $21,000,000 a year for agricultural research in State experiment stations and for State agricultural extension work. In addition, a new Act passed by Congress in 1935 authorizes eventually an additional appropriation of $5,000,000 a year for basic research in agriculture.

Nothing comparable is being done in support of basic research for the advancement of industry. But industry as well as agriculture is a vital factor in our national welfare. Both deserve the assistance of the Government in carrying out the basic research necessary for their development.

One new industry comparable with the automobile industry would bring employment back to normal. The same thing could be accomplished with a number of smaller industries of equivalent output.

To increase employment, these new industries must do more than replace with a new product something already in use. They must create new things that people will want in addition to what they already have.

The whole history of industry is characterized by the fact that new industrial developments follow new scientific discoveries. If the development of new industries is desired, we must foster scientific research and discovery in physics and chemistry upon which developments in industry may be based. If industry is to provide a greater field for employment, we must from some source give it new facts and discoveries with which to work.

Viewed from this standpoint, basic scientific research must play an important part in our national development, as a catalyzer of new industries and a stabilizer in economic tides. Is not its generous support by the Federal government warranted as a sound economic measure?

The Hartmann Acoustic Generator.—(*Engineering*, Vol. CXLII, No. 3695.) A generator of powerful waves in air at high, and even supersonic, frequencies may have useful applications in science and industry. Such a generator was developed by Prof. J. HARTMANN of the Royal Technical College, Copenhagen. The generator, known as the acoustic air-jet generator, and described recently before Section A (Mathematical and Physical Sciences) at Blackpool, can be made to produce frequencies from about 5,000 cycles to 40,000 cycles, or higher, although the output energy diminishes as the frequency increases. While investigating, by means of a Pitot tube, the velocity distribution in a jet of mercury in connection with the Hartmann mercury jet rectifier, Professor Hartmann decided to make a similar investigation on an air jet. From this there resulted very interesting physical phenomena and the acoustic generator. The effect of powerful high frequency sound waves on disperse systems is worthy of particular mention. Tobacco smoke, in a Kundt tube exposed to sound waves produced by the acoustic generator was found to disappear almost instantaneously, the minute smoke particles combining to form larger particles which were precipitated on the lower side of the tube, forming a pattern similar to that produced in the well known experiment with lycopodium powder. Dust and ammonium chloride smoke have been subjected to the sound waves. Some idea of the possibilities may be gathered from a statement by Dr. Hiedemann that, in the case air containing tobacco smoke to the extent of 10^4 mg. per cubic meter, he had been able to reduce the smoke content to 0.03 per cent. of its original value in 10 sec.

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ECONOMIC TRENDS IN MANUFACTURING AND SALES.*

BY

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There was an old professor of economics at the University of Heidelberg who is credited with frequently putting the question on his examinations: "Warum haben wir eine Giesserei." "What is a foundry for?" And only one answer was acceptable, "To make a profit." It is this theme I desire to stress in developing the subject of economic trends in manufacturing and sales. I mean to use the term "economic" not with its usual significance, but in a sense more nearly approximating the Greek meaning of the word, namely, "household management."

I would like to provide a practical guide to sound administrative thinking. Much has been written on the subject of business management and business organization from a technical point of view, most of it confusing to the general business executive who has not learned to think along technical organization lines. Many of these books have great merit in that they develop principles which have universal application, but they are often difficult to translate into practical terms applicable to a particular business. In order that the principles thus enunciated may be useful to ordinary business, whether large or small, men trained in the academic point of view from which such literature is written and also experienced in business management, are needed to translate principles into clear and simple terms which busy men can readily understand.

There has been too little said which places sufficient emphasis on the human side of the organization problem, and it is this human variable which I will have occasion to stress several times in the course of this lecture. Two pertinent

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illustrations of my meaning have to do with the organization chart and the functions of the chief executive. The organization chart is an essential to any business however small, and when well-drawn it represents an ideal towards which the chief executive can work. And it is necessary at any time to have charts drawn expressing the actual as well as the ideal condition, because the personnel to perform all the various duties indicated by the ideal chart as they should be done is rarely available, and, pending the development of such personnel, modifications in a projected ideal organization are necessary.

A usual designation of the functions of the chief executive is: first, the determination of policy; second, the administration of public contacts; third, organization planning; fourth, coördination of personnel in the functions of the business; but such a catalog of responsibility leaves out what is really his most important function, and the one which has more to do with the success or failure of the enterprise than any other, namely, the inspiration of enthusiasm in the organization, a thing without which a business is but a dead thing.

The subject of the economics of manufacturing and sales is all-embracing, as it involves practically the whole of business, and it is obvious that in an address such as this, one can do no more than touch upon some of the high spots and indicate generalities of thought along lines that are becoming standard in American business management. The vicissitudes through which business has passed since 1929 have resulted in the failure of many business institutions which in their various lines had become by-words for profitable and successful business operation over a period of many years. Many concerns have fallen by the wayside which had come to be regarded by the public as immune to any business catastrophe. Almost without exception such failures have been primarily due to inability or unwillingness on the part of the management to recognize a fundamental change in conditions. Many of the old institutions which had been profitable for decades but which had experienced variations in the degree of their prosperity regarded the present condition as just another decline from the peak. They expected that shortly everything would right itself as it had done in the past, and that the

system and methods of the founders of the business and their successors, having borne the test of time, were the ones and the *only* ones. But few of the businesses which maintained this philosophy have survived, and these few only because those responsible for the management had an intuitive sense of such inherent soundness that they were able to follow the trends of the times more or less subconsciously.

I recently had the privilege of examining the workings of a very old business which is thoroughly successful and which for many years prior to 1929 had been the leader in its industry. The present chief executive is operating the business on the most modern lines possible, every device available for the successful conduct of business having been applied with the utmost intelligence. I said to him, "How is it that this business succeeded for so many years with none of these methods which you have successfully installed and which are so evidently responsible for your present success?" His reply was that when the business succeeded on the old methods, no competitor knew anything about the new ones, and where no one's methods were any more efficient, it was able to compete at a profit, whereas now anybody attempting to ignore the new ideas pertinent to the profitable conduct of business would soon fail.

The effect of the work of Taylor and Gantt on modern methods cannot be overestimated. Their contribution marks the beginning of as different an era in business management throughout the world as the application of steam power to machinery by Watt and Newcomen brought to our industrial system.

These revolutionary changes have proved an opportunity for business engineers and experts in sales and production management and accountancy to sell their services, often to the great advantage of the enterprises employing them. And the value of the industrial report has increased progressively. With some, these business reports have fallen into disrepute which they do not deserve, because some reporting organizations failed to understand that it is useless to furnish a man with a tool unless he knows how to use it. I have in mind a report by one of the ablest business engineering firms in the country, prepared at the instance of the Board of Directors of

a large industrial institution who instinctively felt that the management did not fully appreciate the problems which were inherent in a new era of the business. The report is one of the best I have ever seen. It is in two large volumes, furnishing a comprehensive survey of the entire industry and an exhaustive examination of this particular unit. It goes into all of the detail of manufacture and sales, reviewing them most ably. The report cost $40,000 and its preparation took fourteen months. But it would have been just as sensible to give a dirt farmer a fine milling machine to operate without any instruction, as to have furnished that management with such a tool. In spite of specific and eminently sound recommendations of what to do, of changes to be made and so forth, the management in question was completely at a loss how to apply them, and the two volumes remain undisturbed and unread in the safe. This is an instance of what occasionally happens, and in my opinion it is the duty of organizations writing such reports to be assured before taking their client's money, that the tool which they undertake to furnish to him is one which he may have a reasonable hope of using to his advantage. This is no alibi for the managements. Obviously they should be able to use all of the devices which modern scientific method places at their disposal, and if they have become so old and outworn that they cannot adapt themselves to the new methods, they should voluntarily stand aside and let the enterprise be conducted by somebody with a more modern mental equipment. However, this is too much to expect of human nature in all but exceptional cases. Having looked at many and varied organizations I confess to surprise at finding how outworn and unsound is the thinking of some of the executives, from our modern viewpoint. Sometimes it is hard to believe that the corporation under observation could ever have been successful with ideas which today seem so strange that it is incredible that they could even have been entertained without vital injury to the enterprise. But it must be borne in mind that many of the old line organizations succeeded in spite of their persistence in certain errors because other qualities which they possessed were outstanding and so superior to those of their competitors that their business was profitable even though there were substantial elements of fallacy in many of their operations.

To illustrate what I mean: A certain corporation, a leader in its industry in the United States, had paid a very satisfactory profit over a period of years and had accumulated a large surplus. This success was based on its superior ability to produce novel and attractive merchandise, and to have a line of goods which, on account of the superior skill with which it was made, gave it a preëminent place. The concern in question made highly styled, seasonable merchandise, and had never used any system of inventory control which enabled it to know how much of its inventory was carried over from one season to the next. The management had the idea that when some of its merchandise was left over from a season and could not be sold except at a sacrifice, it was better to carry it over than to make the sacrifice necessary to sell it, on the theory that the most it could cost them would be six per cent. on the amount involved and that after charging this six per cent. against the merchandise in question, the goods could still be sold at a better price the next season than if they were forced upon the current market. They were more than surprised when I called their attention to the fact that the six per cent. which they had figured as the cost of carrying the merchandise over was but a small fraction of what they actually spent; that in spite of their excellent financial condition, every dollar's worth of idle merchandise which they had on their shelves interfered with the sale of merchandise which should have been active, particularly since in the industry in question an inventory turnover of six times a year was normal with an expected gross profit of about seven per cent. In other words, there was a 42 per cent. gross profit per annum to be expected on the amount of money invested in their inventory, so that if they had merchandise which was idle for six months, it prevented investment of the company's money in merchandise which should have been producing 21 per cent. gross in that period. This entirely apart from the six per cent. per annum which they figured as the cost of the money employed with no allowance for the cost of insurance, storage or time and effort of the executive and selling departments. Moreover when the season for selling the merchandise recurred, it constituted an interference with the marketing of the current line for that season, so that in this particular

business the cost of carrying merchandise from season to season was much more nearly 50 per cent. per annum than 6. And yet, in spite of the company's failure to recognize so perfectly evident and fundamental a condition, the business succeeded for many years. How much more successful it would have been had the executives been able to grasp such a simple principle of economical management!

Ability to analyze scientifically the circumstances surrounding a business is much rarer than it should be even in our day and generation. But it was almost wholly absent from the scheme of operation twenty years ago. Some minds work well with the use of formulæ, and for such I have devised a very simple one which has the merit of expressing in the briefest form all that goes with the successful management of business. It is as follows:

Where working capital is represented by W, and T represents turnover, then

$$WT = V \text{ (which is volume).}$$

Where the rate of gross profit is represented by P then

$$VP = \text{total gross profit for the business.}$$

If you represent the overhead of the business by O and the net profit by P_n, we have the equation:

$$VP - O = P_n,$$

and substituting for V its equivalent, WT, we have the equation:

$$WTP - O = P_n,$$

or, in ordinary English: Working capital times turnover, times rate of gross profit, less overhead expense results in the net profit of any enterprise. From this it is evident that an increase in net profit is obtained either by an increase in working capital, an increase in turnover, an increase in rate of gross profit or a reduction in overhead of all four. And all of the corollaries to the proposition are corollaries to profitable business management. For example:

If you have a seasonal business in which the turnover can only be once a year, the gross profit must be very large in

order to justify the employment of working capital and the payment of ordinary overhead. The corollary to that is that if the gross profit can't be large in a business which can only have a turnover once a year, you mustn't try to do that kind of business. Such a conclusion is inevitable. In the formula which we have just developed, the item of turnover is such an important one that it would be difficult to say too much about it. It is perhaps the most important factor in the equation, and certainly the most important factor in its term. But few managements are so bad that they attempt to manufacture merchandise without any gross profit. A small rate of gross profit, nevertheless, on sales, can be converted into a handsome total gross profit by an adequate increase in the rate of turnover. The rate of turnover of working capital is increased principally, first by shortening the terms of sale, and second by decreasing the amount of inventory while maintaining or increasing sales. The matter of terms of payment is so much a custom of an industry that management is apt to dismiss the matter of change in this respect as impossible. I have in mind an instance of an industry in which for many years terms of payment of 2 per cent. ten days with 60 days dating had been universally established. A new corporation came into the industry with a rather limited capital but with an ambition to do as much business as their larger competitors. They established the terms on which they would sell merchandise at 3 per cent. ten days with end of the month dating, and for years were successful in selling all of the merchandise which their capital permitted against the unchanged terms of their competitors, an accomplishment which everyone had regarded as out of the question.

The equation I have given you expresses the factors, and *all* the factors, which must be worked upon in order to accomplish net profit in an enterprise. It seems so simple as to be almost unnecessary to express it in this way. But all business is just as simple as that equation.

Perhaps this is as good a place as any to tell the story of the man who went to consult one of the most successful Jews in American business. What he said was: "I want to ask you a question which I hope you can answer, and which I hope you

will be willing to answer. You will understand I am asking it with the greatest respect for the business ability of your race. I am going into a new enterprise, and before I do so, I want to know what quality it is which the Jew has which makes him more successful as a rule in certain types of business enterprise than his Gentile competitor."

And the reply came, quick and to the point: "The successful Jew's business method is exactly the opposite of that usually employed by his competitors of other races. The Jew determines what he wants his end result to be and works backwards from it, doing all the things which it may be necessary to do to accomplish that result. He starts from a known, expected or hoped-for net profit, and his overhead is no larger than is consistent therewith, and his turnover and gross profit are made to be consistent with the net profit desired in consideration of the working capital which is available. On the other hand, the Gentile is prone to approach the problem by conceiving that an enterprise employing a certain amount of money in fixed assets and in working capital may be profitable, and then he proceeds to see how much money can be made." If you take the trouble to follow the thought of our Jewish friend a minute, you will see the inherent merit of his idea. It is, after all, a fundamental plea for budgetary control.

The matter of inventory volume in relation to total sales is the point at which many corporations fail when it comes to attempting a rapid turnover of the working capital, because this matter of the volume of merchandise which it is necessary to have on hand in order to accomplish a given volume of sales is one which is quite difficult of analysis and involves most of the elements of the business. For instance, if we consider a business which has two active seasons, the manufacturing may be handled in several different ways. It would be possible in one case to increase the amount of fixed capital invested in a plant to the point where the merchandise could be currently produced in each season. On the other hand the amount of fixed capital could be so far curtailed that the manufacturing operation could continue at an even rate throughout the year with the merchandise inventory going to two peaks in the two seasons of least activity. As a rule this

latter method, when practical, is the better, because while inventories are a business hazard which we have ever with us, large capital investments are a much greater hazard and are subject to all of the ills which are peculiar to capital investment and which do not inhere in investment in inventory. Many businesses manufacturing a large number of items consider it desirable to have a sufficient amount of merchandise on hand at all times to be able to immediately service all sales which may be made. Of course it is perfectly practical to build such an inventory, but rarely is it economically sound to do so. It will very often be found that it is much better to have the customer wait or get into the habit of anticipating his needs, or even to pass up the business because the merchandise is not available at the time than to try to consummate all sales by having a plethora of merchandise. It's a matter of balancing, and by applying the formula which I have already developed, one determines whether or not the reward in profit is sufficient to justify the expense of the inventory. If it is not, you simply can't afford to have the inventory. All inventory control must provide for the aging of the inventory. Management must at all times know accurately just what part of its stock on hand is current, six months old, one year old, two years old, etc. When this information is currently available to the head of a business, there is little obsolete merchandise.

Banks always press to have the inventories of their borrowing clients at the lowest possible point because so many losses have been due in the past to failure of their clients resulting from a depreciation of inventory. What the banks really mean is that a statement looks most attractive to them when the inventory of *slow-moving* goods is at its minimum. The banks know as well as anybody else that the best security in the world is merchandise which is moving rapidly in trade. One of the large food chains turns their total inventory once every three weeks. There is no bank in the country which if it had the resources available would not lend them the *total value of their inventory* on the basis of its speed of turnover, even if it were in much less favorable financial circumstances than is the case. I just said that there were very few managements so foolish as to manufacture

merchandise without some gross profit. But in some industries, it has been the practice with many managements to continue to operate their plants if the loss which they sustained in selling their merchandise did not exceed the amount of money which was represented by the fixed charges on the plant when idle. There is practically never any excuse for such reasoning. The excuse so often given by manufacturers who pursue this policy, that great loss is involved in the disruption of their organization through shut-down has a good deal of sophistry in it. To reopen a closed plant when the organization has been disrupted is a difficult task, but by no means an impossible one, and it is a difficulty which must be recognized as inherent in any situation where there is not a profitable market available. To force merchandise at a loss upon an unwilling market is only to weaken that market, and accumulation of inventory is as detrimental to price structure as the actual pressure to sell.

I would like to emphasize how closely the matter of capital investment is bound up with maintenance, inventory and depreciation, because a restriction of capital investment makes so great a contribution to the diminution of overhead. Very careful studies have to be made which will involve the relation between these four items for any given business. It is evident that as the capital investment increases, so maintenance and depreciation increase, but with greater capital investment, as I have said above, it is possible to operate with a smaller inventory. The accrual of depreciation on plant is rightly regarded as a fundamental necessity in accounting. It is my belief that it is equally important to accrue a reserve for obsolescence of inventory unless it can be shown that the turnover is so rapid and certain and the product has so low a style element in it that it suffers no depreciation in its normal inventory life.

And that brings me to the next item which I want to talk to you about, which is the budget. So much has been said about budgets and so little understood! No human enterprise, whatever it may be, can be as successfully conducted without a budget as it can be with one. To say that a business cannot be conducted without a budget is to say something that obviously is untrue because many businesses are

conducted without budgets and have been for many years, and have nevertheless made a profit. The merit of budgetary control, however, is coming to be more generally realized, and in the course of a short time will be universally applied. In the many businesses with which I have been familiar, it is surprising how often I have met the statement, "Well, you can budget a lot of businesses, but you can't budget ours. It is simply impossible to express our business in budgetary terms." Now, of course everybody here knows the fallacy of such a remark. There is no such thing as a business which cannot be budgeted, or at any rate, if there is, I don't want to have anything to do with it. But I find that many people who regard the budget as impractical for their businesses fail to understand what a budget is all about. In the first place there are several kinds of budgets. There is the Treasury Budget which has for its main object the advising of the executive who is responsible for the financing of the operation, and which aims to tell him what money he must provide for the expected operations of the business. Or looking at it the other way, it is the document which enables the financial executive to tell those responsible for operations how much money is available. Then there is the Sales Budget which attempts to reflect what the accomplishments will be over the period covered by the budget. It is here that the most noticeable difference exists between the functions of the various budgets, because a Sales Budget with no element of hope in it is but a poor document, but it is evident that if a project of sales which reflects hope and ambition for a greater accomplishment is made the basis of a manufacturing schedule, the business is very likely to have on its hands more inventory than is desirable. The Manufacturing Budget must also have in it an expectation of accomplishment not theretofore realized. But again it is evident that if the costs projected in such a budget were to be used as a basis for pricing one's merchandise, there might be an inadequate gross profit. Therefore, the fourth kind of budget which is necessary is the Administrative Budget, in which the judgment of the budgeteers is employed to determine the probability of accomplishment against the standards set up by the Sales and Manufacturing Budgets, and which endeavors to present as nearly

true a picture of what is going to happen as is possible. As a rule, budgets which look forward to operations more than four months in advance are unsatisfactory on account of the many variables which develop in the course of time. The best practice, I believe, in most cases is to develop four-month budgets, making a new set each month and each month dropping off one month and picking up another.

Many of those who deprecate the use of a budget system are of the opinion that in order to be a success a budget must accomplish approximate accuracy, in other words, the results must be very nearly in accordance with the prophecy. My conception of budgeting is that this isn't the function of the budget at all, and that the accuracy of a budget is *relatively* unimportant. To my mind a budget represents a standard, a measuring stick with which to measure the accomplishment of the various activities of the business. Of course, a budget must tie into the books, and in this sense it must be as accurate as any of the accounting. It must be prepared with the greatest of care and with proper regard to detail. A Sales Budget which reflects total sales on a basis of seasonal activity and is related to a previous season's accomplishment is not properly made unless it is checked by the detail statements of expected results to be brought in by each sales department, by each branch and by each salesman. And each salesman should be made to budget his customers so that he shows the expectancy of business to be realized from each. Only by so doing can the sales department evaluate its accomplishment against the project. Salesman John Brown has 45 customers. He has succeeded in getting 22 of them to try samples of his line. From these 22 he expects next month to sell varying amounts of merchandise depending upon the size of the prospective customer's business, his financial condition, business activity, etc., all of which the salesman should be taught to evaluate. When the end of the budget period comes, and the comparison of the budget figures is made with the actual results, he finds that of the 22 customers he had expected to bill in the period under review, 16 of them have bought less than projected. And then when he comes to analyze why he made the prediction, he finds out what his own deficiencies were in presenting his merchandise, as well

as his deficiencies in evaluating his customers. He finds, for instance, that one of his customers whom he had been depending upon as a substantial source of business has failed, and that puts him on notice that he should be careful not to spend his time on the development of business with individuals whose credit is doubtful. He finds in respect to another customer that he has not properly evaluated his activity in the particular line of merchandise which he is selling. And that puts him on notice to be more careful in ascertaining just what his customers' activities are. And so on through his entire line of accounts until after a number of months of such painstaking analysis, he is able to devote his energies to the production of more business in a more rational and intelligent way. He is also able to reflect to his superior more accurately what results should be expected from him, and if his superior has adequately studied the salesmen under his control, he will have learned how much allowance to make in the case of each salesman for errors in his estimates. Obviously the less adjustments he is obliged to make, the more useful the figures will be, and the better will be the manufacturing schedule which is worked from the sales projected.

A similar line of reasoning is applicable to the manufacturing department. The manufacturing department has to be able to manufacture the product for a certain cost, all of which is within the lines of reasonable expectation. Then, when the product is made and the cost is higher than expected, they make inquiry as to where the differences exist, and are thereby put on the road to better accomplishment. To repeat: these budget figures should be something whereby each person in the organization can measure what is his per cent. of accomplishment against a standard.

Any religious or moral code is merely a budget by which the individuals in the society attempt to so conduct themselves that they can be useful members of that society. The Ten Commandments are a budget of living according to the Mosaic System. The ancient Hebrews, knowing they were individually going to fall short of the rules laid down for them, nevertheless recognized the merit of budgeting their moral and social lives so that they could measure the quality of their citizenship. In the Roman Catholic confessional the

devout Catholic attempts with the aid of the priest to measure the accomplishment of his living over the period under review against the code or budget laid down by his Church. That the standards of conduct should have been budgeted by so many peoples for so many thousands of years without the budgeteering idea being applied to business until very recently, and not adequately even now to the management of governmental affairs, is a matter of wonder.

Budgetary control about which we have just been speaking is closely related to cost accounting, but before I touch upon what I have to say about cost accounting, I would like to say a few words about the compilation of statistics and figures in general. Figures in regard to any business are not worth the cost of compiling them unless action can be predicated upon them. A set of figures taken as an historical document is of little merit in a business. All banks should require balance sheets from all accounts before making loans, and most banks do. But a balance sheet as of January first is of no value in guiding the bank officer to a loan which is going to be made on March 15, except as a general indication of the proper soundness of the business. What the lending officer is interested in is not what the company had on January 1st, or even on March 15th, but what it is going to have on the day the loan comes due. A concern making a statement to a bank which reports its financial condition as of a given date and showing millions of surplus and cash on hand may, nevertheless, at the time it is making the loan, be ruined by the contracts to buy or sell which it has made in the interim; which is only saying that it is the future which counts and not the past. Similarly, no concern should bother with budgeteering unless it intends to make the budget the code by which it lives, unless it intends to minimize thereby the faults of sales, manufacture and administration and remedy them. I have been associated with businesses which accumulated figures by volumes, many of which figures were never used by anybody and merely constituted a record. Such figures had better not be made. They cost a lot of money and get nobody any place. A very interesting illustration of this occurred in a business which had a plant investment of about $15,000,000 with thousands of units of equipment. When I

first became acquainted with the concern, they had the most complete property record of equipment I have ever seen. Each unit of property had a card, and on each card was recorded the date of acquisition, the price paid, from whom purchased, the depreciation of that particular piece of equipment, the maintenance on it and its expectancy of life. It took 45 clerks to maintain the records, and it was of very little value. Certainly the value was wholly incommensurate with the cost of keeping the record. Theoretically, if a unit of equipment needed repair, the maintenance department called for the card, made a study of the original cost and what had been spent on it, and basing their opinion on this study, determined how much they could justify spending on the unit in the light of its present condition. As a matter of fact, when a piece of apparatus needed repair, the quicker and more efficient way to determine what to do was to have an able maintenance engineer go out in the plant, inspect the piece of equipment and from its condition and cost of repair called for, determine whether or not it was worth while to make the repair. There was rarely time to stop to make a study of the record. The loss of the use of the equipment in question for the additional time necessary to go through the details recorded, always resulted in a greater loss than any possible theoretical saving which could have been made by managing it this way. The company threw out the property record it had kept and reduced the number of clerks by 30 with no loss of efficiency. This is just one illustration of a case where a theoretically ideal system cannot be justified on account of its expense against the more practical method which was thereafter employed. This is not to say that an adequate property record may not be of great value to a business, for I am merely illustrating the point that there is no system, however sound, applicable in all its details to all businesses. It must be determined in each case just how far one is justified in going in the preparation of data, *for the merit of figures lies wholly in the use to which they are put.* Most business managements recognize the fact that figures to be of interest must be comparative, showing the progress which is being made, to accomplish an ideal in relation to the past, and they must contain an element of expected betterment in the future.

And now specifically as to cost systems. What is a cost system for? Obviously for several purposes. There is a popular idea that a cost system is to enable management to properly price merchandise. This may or may not be so. Comparatively little merchandise is sold on a cost-plus basis. Most merchandise is priced on the basis of market, and market is determined by what competitive articles are offered for, or, in the case of the articles where competition does not exist, the maximum price at which one can obtain the maximum distribution. A cost system is to enable an organization to make a study of various elements that enter into costs in order to determine what may be done to manufacture the article for less money and thereby increase the profits of the business, or to reveal the fact that no lowering of cost is possible, in which case, unless there is an adequate gross profit to justify the overhead, one discontinues making the article. Now, just as every business has to have a budget, so every business has to have a cost system. But a very large number of the cost systems which are in use in modern business are of little or no value. I suppose from the point of view of the accountants, this may be a very heretical statement, but it is surprising how little intelligence is applied to this phase of modern business management. Many volumes have been written on cost systems. And the relative merits of standard and unit cost systems have been proclaimed by the proponents of each, times without end. The fact is that a cost system must be adapted to the particular kind of business in which one is engaged, and for some businesses the standard cost system is ideal—in others it isn't worth anything at all. In some cases direct unit costing is the only one which is applicable to the particular problem, and in other cases, direct unit costing is much more expensive than is necessary for the operation. For instance, in a plant making car wheels and nothing else, a standard cost system is operated under ideal conditions. A shoe factory making three kinds of the same class of shoe of the same approximate grade, where variations in total output and in relative output between the various articles does not vary substantially, a standard cost system also works fairly well. But I have seen a business operating under a standard cost system where the activity of the plant fluctuated as much as 25 per cent. from month to month, where each order was in

effect a special order and where the variation in ratio between the various types of merchandise fluctuated violently. In such a case I can find no merit whatever in the standard cost system. It contains so many variables and is subject to so much error that it furnishes no reliable guide to the management for improvement in manufacturing methods or economies in the use of raw material and as a record is of little use because the comparison of the accomplishment from month to month is wholly obscured by the dissimilarity of the operation in one month to that in another. One of the businesses which I have in mind of which this is particularly true was nevertheless very profitable, but its profit-making ability was due not to the guidance of its cost system towards determining the price at which the merchandise should be sold, but to lack of competition in the line.

It will be found as a rule that direct unit costing where the plant makes a large variety of products and where the volume of production fluctuates rapidly is much sounder and gives the management much more of an opportunity to correct its errors and improve its performance than is possible with standard costs. Right here I might say a word about the importance of speed in the production of figures which are to be used. It is surprising how little appreciation there is of the importance of having the figures at the earliest possible moment. In almost any business, however complicated, with the modern methods and the mechanical aids which are available—Hollerith machines, comptometers and so forth—balance sheets, profit and loss accounts and individual detail cost sheets should be available not later than the fifth of the following month. In many cases accounting departments are so organized that these figures are not ready for the management until the latter half of the month, and in some cases even later than this. Figures a month old are of little value. Too much water has gone over the dam since the events happened which the figures record. And errors which are discovered have been persisting for a long time with consequent loss, which losses could have been avoided by a more prompt submission of the figures and their analysis. The best accomplishment along these lines within my experience was by a concern manufacturing 400 products in amounts varying from a few pounds to several hundred thousand, and in vary-

ing volume, which had its accounts so organized that complete cost sheets of each product and balance sheet and profit and loss accounts were available for the executives never later than the fourth of the following month, and many times as early as the second, and this without any undue expenditure for clerical help. To illustrate how careful this concern was in the matter of expenditures for clerical help, the entire billing of $17,000,000 worth of business was done by two billing clerks, although the products were sold to a total of about 3,000 customers in amounts varying from a few ounces to carload lots. It's just a matter of organization and study. Anybody can do it who will take the time and trouble. In this matter of speed in accounting there is more patience with the "can't-be-dones" than in almost any other activity, prominent as the "can't-be-dones" are in all lines of human endeavor.

Let me call your attention, while we are on the matter of manufacturing and administrative phases of business, to the question of capital investment and the necessity for very careful analysis of all proposed capital expenditures. All disbursement of funds is of course of vital importance to the business, and nothing should be disbursed without the greatest care. While extravagance in the payment of salaries is greatly to be deplored, it is far less a fault than extravagance in capital expenditure. You can always stop payments to personnel, but when you have invested a dollar in capital assets, you are thereby committed for all time to the expenditure of at least 15 cents a year at the very minimum, and this expenditure nothing on earth can stop other than the abandonment of the item in question, and even then it bears a tax burden. Therefore when you spend money on earning assets, if you can't be assured that the dollar spent will produce 15 cents a year, don't spend it. Don't erect a building with a fifty-year life to house equipment when the obsolescence in your line is so great that the building may be inadequate for the new equipment developed in the industry inside of ten years. The sin of over-specification is rife in all business. Many go on the supposition, "Be sure that it is good enough," not on the idea, "Be sure that it is economically justified." Over-specification is the device of the lazy man who instead of studying his problem and being sure that he has specified

an adequate life or quality and no more, and pays for no more, arbitrarily writes a specification which will insure quality far in excess of that which can be justified. You must be just as sure that your merchandise is not too good as you are sure that it is good enough. Another way of stating the same thing in connection with the sale of your product is: be sure that you are paid by your customer an adequate price for the quality which you deliver. This may sound somewhat heretical but quality after all is a relative term and nobody attempting to make a glove to retail for $2 believes that he must make one which is as good as one which sells for $6. Provide maximum quality within the range of your product, but be sure you are paid for it. And payment may be constituted by the volume which you get as recognition for your superior quality, just as much as by an increase in the unit sales price.

An interesting development of the times has to do with the fact that in most lines of merchandise, standard advertised, well-known brands command a much smaller premium over less-known competitive merchandise than was formerly the case. It used to be that standard brands of cotton goods could be sold for 5 per cent. to 10 per cent. more than competitive merchandise. Today, all that can be commanded by a well-known name is preference at the same price, which, to be sure, in a well-managed enterprise, is as much as any management should need. Many of the old managements rested on the established good-will of their product and passed on to failure because they depended upon reputation without doing anything to make the economy of their operation consonant with the times. The great leveling process which has been going on in social institutions throughout the world finds its reflection in the merchandise offered to the people now as compared with twenty years or more ago. In most lines there has been a leveling up accompanied in some lines by a leveling down. The food chain store has made available to the masses of the people much better food at a lower cost than could formerly have been bought from the small individual food store serving the industrial community. At the same time it has narrowed the market for quality foods to the point where it is very difficult to operate very high-class food stores at a profit except in large metropolitan areas. The same is

true of clothing and many other lines. A full discussion of this phase of sales is wholly impracticable within the time available to me. The general basic principles universally recognized in connection with the distribution of all merchandise, relate to the creation in the mind of the prospective purchaser of an effective desire, and modern sales methods which attempt to create or increase the effective desire for an article have a tremendous bearing upon our whole economic life. From the sale of a pack of cigarettes to an individual to the sale of the George Washington Bridge or the Pulaski Skyway to a community, the stimulation of effective desire is the necessary thing before a sale can be accomplished. In our modern life there has been so much artificial stimulation to effective desire that when we fail to maintain it at the level which we have developed, and there is a natural recession in that particular field, our whole structure is affected. And when this slump in effective desire takes place in a substantial part of the buying activities of the nation, an economic catastrophe develops. There is a school of economics which holds that there can be no such thing as overproduction until all wants of the community are satisfied, and inasmuch as each one wants to live a fuller life than he is living at any given time, his wants are never satisfied, and therefore the potential market is always far in excess of our productive ability. Like so many theories, this is fine except that it leaves out the one essential element and that is the degree of effectiveness of the want or the desire, or in other words, how much effort the individual or community is willing to put back of his or its desire to accomplish the end. All the people who have two suits of clothes presumably would like to have four, but will they work the additional time or make the more intense effort necessary to accomplish this end? If they will not, their desire for the other two suits of clothes is ineffective and as related to the clothing industry has no validity whatever.

In conclusion let me stress what I consider to be the most important thing which I have said tonight; namely, that the chief function of the chief executive is the inspiration of enthusiasm in his organization. And he must so constitute the channels for the dissemination of this enthusiasm that it reaches the lowest worker undimmed and undiminished.

ON GRAVITATIONA WAVES.

BY

A. EINSTEIN and N. ROSEN.

ABSTRACT.

The rigorous solution for cylindrical gravitational waves is given. For the convenience of the reader the theory of gravitational waves and their production, already known in principle, is given in the first part of this paper. After encountering relationships which cast doubt on the existence of *rigorous* solutions for undulatory gravitational fields, we investigate rigorously the case of cylindrical gravitational waves. It turns out that rigorous solutions exist and that the problem reduces to the usual cylindrical waves in euclidean space.

I. APPROXIMATE SOLUTION OF THE PROBLEM OF PLANE WAVES AND THE PRODUCTION OF GRAVITATIONAL WAVES.

It is well known that the approximate method of integration of the gravitational equations of the general relativity theory leads to the existence of gravitational waves. The method used is as follows: We start with the equations

$$R_{\mu\nu} - \tfrac{1}{2}g_{\mu\nu}R = -T_{\mu\nu}. \tag{1}$$

We consider that the $g_{\mu\nu}$ are replaced by the expressions

$$g_{\mu\nu} = \delta_{\mu\nu} + \gamma_{\mu\nu}, \tag{2}$$

where

$$\begin{aligned} \delta_{\mu\nu} &= 1 \quad \text{if} \quad \mu = \nu, \\ &= 0 \quad \text{if} \quad \mu \neq \nu, \end{aligned}$$

provided we take the time coördinate imaginary, as was done by Minkowski. It is assumed that the $\gamma_{\mu\nu}$ are small, i.e. that the gravitational field is weak. In the equations the $\gamma_{\mu\nu}$ and their derivatives will occur in various powers. If the $\gamma_{\mu\nu}$ are everywhere sufficiently small compared to unity one obtains a first-approximation solution of the equations by neglecting in (1) the higher powers of the $\gamma_{\mu\nu}$ (and their derivatives) compared with the lower ones. If one introduces further the $\bar{\gamma}_{\mu\nu}$ instead of the $\gamma_{\mu\nu}$ by the relations

$$\bar{\gamma}_{\mu\nu} = \gamma_{\mu\nu} - \tfrac{1}{2}\delta_{\mu\nu}\gamma_{\alpha\alpha},$$

then (1) assumes the form

$$\bar{\gamma}_{\mu\nu,\ \alpha\alpha} - \bar{\gamma}_{\mu\nu,\ \alpha\nu} - \bar{\gamma}_{\nu\alpha,\ \alpha\mu} + \bar{\gamma}_{\alpha\alpha,\ \mu\nu} = -2T_{\mu\nu}. \tag{3}$$

The specialization contained in (2) is conserved if one performs an infinitesimal transformation on the coördinates:

$$x_\mu' = x_\mu + \xi^\mu, \tag{4}$$

where the ξ^μ are infinitely small but otherwise arbitrary functions. One can therefore prescribe four of the $\bar{\gamma}_{\mu\nu}$ or four conditions which the $\bar{\gamma}_{\mu\nu}$ must satisfy besides the equations (3); this amounts to a specialization of the coördinate system chosen to describe the field. We choose the coordinate system in the usual way by demanding that

$$\bar{\gamma}_{\mu\alpha,\ \alpha} = 0. \tag{5}$$

It is readily verified that these four conditions are compatible with the approximate gravitational equations provided the divergence $T_{\mu\alpha,\ \alpha}$ of $T_{\mu\nu}$ vanishes, which must be assumed according to the special theory of relativity.

It turns out however that these conditions do not completely fix the coördinate system. If $\gamma_{\mu\nu}$ are solutions of (2) and (5), then the $\gamma_{\mu\nu}'$ after a transformation of the type (4)

$$\gamma_{\mu\nu}' = \gamma_{\mu\nu} + \xi^\mu{}_{,\nu} + \xi^\nu{}_{,\mu} \tag{6}$$

are also solutions, provided the ξ^μ satisfy the conditions

$$\left[\xi^\mu{}_{,\nu} + \xi^\nu{}_{,\mu} - \tfrac{1}{2}\delta_{\mu\nu}(\xi^\alpha{}_{,\alpha} + \xi^\alpha{}_{,\alpha})\right]_{,\nu} = 0,$$

or

$$\xi^\mu{}_{,\alpha\alpha} = 0. \tag{7}$$

If a γ-field can be made to vanish by the addition of terms like those in (6), i.e., by means of an infinitesimal transformation, then the gravitational field being described is only an apparent field.

With reference to (2), the gravitational equations for empty space can be written in the form

$$\left.\begin{aligned}\bar{\gamma}_{\mu\nu,\ \alpha\alpha} &= 0.\\ \gamma_{\mu\alpha,\ \alpha} &= 0.\end{aligned}\right\} \tag{8}$$

One obtains plane gravitational waves which move in the

direction of the positive x_1-axis by taking the $\overline{\gamma}_{\mu\nu}$ of the form $\varphi(x_1 + ix_4)(= \varphi(x_1 - t))$, where these $\overline{\gamma}_{\mu\nu}$ must further satisfy the conditions

$$\left.\begin{aligned} \overline{\gamma}_{11} + i\overline{\gamma}_{14} &= 0, \\ \overline{\gamma}_{41} + i\overline{\gamma}_{44} &= 0, \\ \overline{\gamma}_{21} + i\overline{\gamma}_{24} &= 0, \\ \overline{\gamma}_{31} + i\overline{\gamma}_{34} &= 0. \end{aligned}\right\} \tag{9}$$

One can accordingly subdivide the most general (progressing) plane gravitational waves into three types:

(*a*) pure longitudinal waves,

only $\overline{\gamma}_{11}$, $\overline{\gamma}_{14}$, $\overline{\gamma}_{44}$ different from zero,

(*b*) half longitudinal, half transverse waves,

only $\overline{\gamma}_{21}$ and $\overline{\gamma}_{24}$, or only $\overline{\gamma}_{31}$ and $\overline{\gamma}_{34}$ different from zero,

(*c*) pure transverse waves,

only $\overline{\gamma}_{22}$, $\overline{\gamma}_{23}$, $\overline{\gamma}_{33}$ are different from zero.

On the basis of the previous remarks it can next be shown that every wave of type (*a*) or of type (*b*) is an apparent field, that is, it can be obtained by an infinitesimal transformation from the euclidean field ($\overline{\gamma}_{\mu\nu} = \gamma_{\mu\nu} = 0$).

We carry out the proof in the example of a wave of type (*a*). According to (9) one must set, if φ is a suitable function of the argument $x_1 + ix_4$,

$$\overline{\gamma}_{11} = \varphi, \qquad \overline{\gamma}_{14} = i\varphi, \qquad \overline{\gamma}_{44} = -\varphi,$$

hence also

$$\gamma_{11} = \varphi, \qquad \gamma_{14} = i\varphi, \qquad \gamma_{44} = -\varphi.$$

If one now chooses ξ' and ξ^4 (with $\xi^2 = \xi^3 = 0$) so that

$$\xi^1 = \chi(x_1 + ix_4), \qquad \xi^4 = i\chi(x_1 + ix_4),$$

then one has

$$\xi^1{}_{,1} + \xi'{}_{,1} = 2\chi', \qquad \xi^1{}_{,4} + \xi^4{}_{,1} = 2i\chi', \qquad \xi^4{}_{,4} + \xi^4{}_{,4} = -2\chi'.$$

These agree with the values given above for γ_{11}, γ_{14}, γ_{44} if one chooses $\chi' = \frac{1}{2}\varphi$. Hence it is shown that these waves are

apparent. An analogous proof can be carried out for the waves of type (*b*).

Furthermore we wish to show that also type (*c*) contains apparent fields, namely, those in which $\overline{\gamma}_{22} = \overline{\gamma}_{33} \neq 0$, $\overline{\gamma}_{23} = 0$. The corresponding $\gamma_{\mu\nu}$ are $\gamma_{11} = \gamma_{44} \neq 0$, all others vanishing. Such a wave can be obtained by taking $\xi' = \chi$, $\xi^4 = -i\chi$, i.e. by an infinitesimal transformation from the euclidean space. Accordingly there remain as real waves only the two pure transverse types, the non-vanishing components of which are

$$\gamma_{22} = -\gamma_{33}, \tag{c_1}$$

or

$$\gamma_{23}. \tag{c_2}$$

It follows however from the transformation law for tensors that these two types can be transformed into each other by a spatial rotation of the coördinate system about the x_1-axis through the angle $\pi/4$. They represent merely the decomposition into components of the pure transverse wave (the only one which has a real significance). Type c_1 is characterized by the fact that its components do not change under the transformations

$$x_2' = -x_2, \qquad x_1' = x_1, \qquad x_3' = x_3, \qquad x_4' = x_4,$$

or

$$x_3' = -x_3, \qquad x_1' = x_1, \qquad x_2' = x_2, \qquad x_4' = x_4,$$

in contrast to c_2, i.e. c_1 is symmetrical with respect to the x_1–x_2-plane and the x_1–x_3-plane.

We now investigate the generation of waves, as it follows from the approximate (linearized) gravitational equations. The system of the equations to be integrated is

$$\left.\begin{aligned} \overline{\gamma}_{\mu\nu,\ \alpha\alpha} &= -2T_{\mu\nu}, \\ \overline{\gamma}_{\mu\alpha,\ \alpha} &= 0. \end{aligned}\right\} \tag{10}$$

Let us suppose that a physical system described by $T_{\mu\nu}$ is found in the neighborhood of the origin of coördinates. The γ-field is then determined mathematically in a similar way to that in which an electromagnetic field is determined through an electrical current system. The usual solution is the one

given by retarded potentials

$$\bar{\gamma}_{\mu\nu} = \frac{1}{2\pi}\int \frac{[T_{\mu\nu}]_{(t-r)}}{r}\,dv. \tag{11}$$

Here r signifies the spatial distance of the point in question from a volume-element, $t = x_4/i$, the time in question.

If one considers the material system as being in a volume having dimensions small compared to r_0, the distance of our point from the origin, and also small compared to the wave-lengths of the radiation produced, then r can be replaced by r_0, and one obtains

$$\bar{\gamma}_{\mu\nu} = \frac{1}{2\pi r_0}\int [T_{\mu\nu}]_{(t-r_0)}dv,$$

or

$$\bar{\gamma}_{\mu\nu} = \frac{1}{2\pi r_0}\Big[\int T_{\mu\nu}dv\Big]_{(t-r_0)}. \tag{12}$$

The $\bar{\gamma}_{\mu\nu}$ are more and more closely approximated by a plane wave the greater one takes r_0. If one chooses the point in question in the neighborhood of the x_1-axis, the wave normal is parallel to the x_1 direction and only the components $\bar{\gamma}_{22}$, $\bar{\gamma}_{23}$, $\bar{\gamma}_{33}$ correspond to an actual gravitational wave according to the preceding. The corresponding integrals (12) for a system producing the wave and consisting of masses in motion relative to one another have directly no simple significance. We notice however that T_{44} denotes the (negatively taken) energy density which in the case of slow motion is practically equal to the mass density in the sense of ordinary mechanics. As will be shown, the above integrals can be expressed through this quantity. This can be done because of the existence of the energy-momentum equations of the physical system:

$$T_{\mu\alpha,\ \alpha} = 0. \tag{13}$$

If one multiplies the second of these with x_2 and the fourth with $\frac{1}{2}x_2^2$ and integrates over the whole system, one obtains two integral relations, which on being combined yield

$$\int T_{22}dv = \frac{1}{2}\frac{\partial^2}{\partial x_4^2}\int x_2^2 T_{44}dv. \tag{13a}$$

Analogously one obtains

$$\int T_{33}dv = \frac{1}{2}\frac{\partial^2}{\partial x_4^2}\int x_3^2 T_{44}dv,$$

$$\int T_{23}dv = \frac{1}{2}\frac{\partial^2}{\partial x_4^2}\int x_2 x_3 T_{44}dv.$$

One sees from this that the time-derivatives of the moments of inertia determine the emission of the gravitational waves, provided the whole method of application of the approximation-equations is really justified. In particular one also sees that the case of waves symmetrical with respect to the x_1–x_2 and x_1–x_3 planes could be realized by means of elastic oscillations of a material system which has the same symmetry properties. For example, one might have two equal masses which are joined by an elastic spring and oscillate toward each other in a direction parallel to the x_3-axis.

From consideration of energy relationship it has been concluded that such a system, in sending out gravitational waves, must send out energy which reacts by damping the motion. Nevertheless, one can think of the case of vibration free from damping if one imagines that, besides the waves emitted by the system, there is present a second concentric wave-field which is propagated inward and brings to the system as much energy as the outgoing waves remove. This leads to an undamped mechanical process which is imbedded in a system of standing waves.

Mathematically this is connected with the following considerations, clearly pointed out in past years by Ritz and Tetrode. The integration of the wave-equation

$$\Box\varphi = -4\pi\rho$$

by the *retarded* potential

$$\varphi = \int \frac{[\rho]_{(t-r)}}{r}dv$$

is mathematically not the only possibility. One can also do it with

$$\varphi = \int \frac{[\rho]_{(t+r)}}{r}dv,$$

i.e. by means of the "advanced" potential, or by a mixture of the two, for example,

$$\varphi = \frac{1}{2}\int \frac{[\rho]_{(t+r)} + [\rho]_{(t-r)}}{r}\, dv.$$

The last possibility corresponds to the case without damping, in which a standing wave is present.

It is to be remarked that one can think of waves generated as described above which approximate plane waves as closely as desired. One can obtain them, for example, through a limit-process by considering the wave-source to be removed further and further from the point in question and at the same time the oscillating moment of inertia of the former increased in proportion.

II. RIGOROUS SOLUTION FOR CYLINDRICAL WAVES.

We choose the coördinates x_1, x_2 in the meridian plane in such a way that $x_1 = 0$ is the axis of rotation and x_2 runs from 0 to infinity. Let x_3 be an angle coördinate specifying the position of the meridian plane. Also, let the field be symmetrical about every plane $x_2 = \text{const.}$ and about every meridian plane. The required symmetry leads to the vanishing of all components $g_{\mu\nu}$ which contain one and only one index 2; the same holds for the index 3. In such a gravitational field only

$$g_{11},\quad g_{22},\quad g_{33},\quad g_{44},\quad g_{14}$$

can be different from zero. For convenience we now take all the coördinates real. One can further transform the coördinates x_1, x_4 so that two conditions are satisfied. As such we take

$$\left.\begin{aligned} g_{14} &= 0, \\ g_{11} &= -\,g_{44}. \end{aligned}\right\} \tag{14}$$

It can be easily shown that this can be done without introducing any singularities.

We now write

$$\left.\begin{aligned} -\,g_{11} &= g_{44} = A, \\ -\,g_{22} &= B, \\ -\,g_{33} &= C, \end{aligned}\right\} \tag{15}$$

where A, B, $C > 0$. In terms of these quantities one calculates that

$$
\left.
\begin{aligned}
2\left(R_{11} - \tfrac{1}{2} g_{11} R\right) &= \frac{B_{44}}{B} + \frac{C_{44}}{C} - \frac{1}{2}\left[\frac{B_4^2}{B^2} + \frac{C_4^2}{C^2}\right. \\
&\quad - \frac{B_4 C_4}{BC} + \frac{A_4}{A}\left(\frac{B_4}{B} + \frac{C_4}{C}\right) \\
&\quad \left. + \frac{B_1 C_1}{BC} + \frac{A_1}{A}\left(\frac{B_1}{B} + \frac{C_1}{C}\right)\right], \\
\frac{2A}{B}\left(R_{22} - \tfrac{1}{2} g_{22} R\right) &= \frac{A_{44}}{A} + \frac{C_{44}}{C} - \frac{A_{11}}{A} - \frac{C_{11}}{C} \\
&\quad + \frac{1}{2}\left[\frac{C_1^2}{C^2} - \frac{C_4^2}{C^2}\right. \\
&\quad \left. + \frac{2A_1^2}{A^2} - \frac{2A_4^2}{A^2}\right], \\
\frac{2A}{C}\left(R_{33} - \tfrac{1}{2} g_{33} R\right) &= \frac{A_{44}}{A} + \frac{B_{44}}{B} - \frac{A_{11}}{A} - \frac{B_{11}}{B} \\
&\quad + \frac{1}{2}\left[\frac{2A_1^2}{A^2} - \frac{2A_4^2}{A^2}\right. \\
&\quad \left. + \frac{B_1^2}{B^2} - \frac{B_4^2}{B^2}\right], \\
2\left(R_{44} - \tfrac{1}{2} g_{44} R\right) &= \frac{B_{11}}{B} + \frac{C_{11}}{C} - \frac{1}{2}\left[\frac{B_1^2}{B^2} + \frac{C_1^2}{C^2}\right. \\
&\quad - \frac{B_1 C_1}{BC} + \frac{A_1}{A}\left(\frac{B_1}{B} + \frac{C_1}{C}\right) \\
&\quad \left. + \frac{B_4 C_4}{BC} + \frac{A_4}{A}\left(\frac{B_4}{B} + \frac{C_4}{C}\right)\right], \\
2R_{14} &= \frac{B_{14}}{B} + \frac{C_{14}}{C} - \frac{1}{2}\left[\frac{B_1 B_4}{B^2} + \frac{C_1 C_4}{C^2}\right. \\
&\quad + \frac{A_4}{A}\left(\frac{B_1}{B} + \frac{C_1}{C}\right) \\
&\quad \left. + \frac{A_1}{A}\left(\frac{B_4}{B} + \frac{C_4}{C}\right)\right],
\end{aligned}
\right\} \tag{16}
$$

where subscripts in the right-hand members denote differ-

entiation. If we take as field equations these expressions set equal to zero, replace the second and third by their sum and difference, and introduce as new variables

$$\left.\begin{aligned} \alpha &= \log A, \\ \beta &= \tfrac{1}{2}\log (B/C), \\ \gamma &= \tfrac{1}{2}\log (BC), \end{aligned}\right\} \tag{15a}$$

we get

$$2\gamma_{44} + \tfrac{1}{2}[\beta_4^2 + 3\gamma_4^2 + \beta_1^2 - \gamma_1^2 - 2\alpha_1\gamma_1 - 2\alpha_4\gamma_4] = 0, \tag{17}$$

$$2(\alpha_{11} - \alpha_{44}) + 2\gamma_{11} - 2\gamma_{44} + [\beta_1^2 + \gamma_1^2 - \beta_4^2 - \gamma_4^2] = 0, \tag{18}$$

$$\beta_{11} - \beta_{44} + [\beta_1\gamma_1 - \beta_4\gamma_4] = 0, \tag{19}$$

$$2\gamma_{11} + \tfrac{1}{2}[\beta_1^2 + 3\gamma_1^2 + \beta_4^2 - \gamma_4^2 - 2\alpha_1\gamma_1 - 2\alpha_4\gamma_4] = 0, \tag{20}$$

$$2\gamma_{14} + [\beta_1\beta_4 + \gamma_1\gamma_4 - 2\alpha_1\gamma_4 - 2\alpha_4\gamma_1] = 0. \tag{21}$$

The first and fourth equations of this group give

$$\gamma_{11} - \gamma_{44} + (\gamma_1^2 - \gamma_4^2) = 0. \tag{22}$$

The substitution

$$\gamma = \log \sigma, \qquad \sigma = (BC)^{\frac{1}{2}}, \tag{23}$$

leads to the wave equation

$$\sigma_{11} - \sigma_{44} = 0, \tag{24}$$

which has the solution

$$\sigma = f(x_1 + x_4) + g(x_1 - x_4), \tag{25}$$

where f and g are arbitrary functions. Eq. (18) reduces to

$$\alpha_{11} - \alpha_{44} + \tfrac{1}{2}(\beta_1^2 - \beta_4^2 + \gamma_4^2 - \gamma_1^2) = 0. \tag{18a}$$

Equation (17) then shows that γ cannot vanish everywhere.

We must now see whether there exist undulatory processes for which γ does not vanish. We note that such an undulatory process is represented, in the first approximation, by an undulatory β, that is by a β-function which, so far as its dependence on x_1 and also its dependence on x_4 is concerned, possesses maxima and minima; we must expect this also for a rigorous solution. We know about γ that $e^\gamma = \sigma$ satisfies the wave equation (24) and therefore takes the form (25). From this, however, the undulatory nature of this quantity

does not necessarily follow. We shall in fact show that γ can have no minima.

Such a minimum would imply that the functions f and g in (25) have minima. At a point (x_1, x_4) where this were the case we should have $\gamma_1 = \gamma_4 = 0$, $\gamma_{11} \geqq 0$, $\gamma_{44} \geqq 0$. But by (17) and (20) this is impossible. Therefore γ has no minima, that is it is not undulatory but behaves, at least in a region of space arbitrarily extended in one direction, monotonically. We shall now consider such a region of space.

It is useful to see what sort of transformations of x_1 and x_4 leave our system of equations (14) invariant. For this invariance it is necessary and sufficient that the transformation satisfy the equations

$$\left.\begin{aligned} \frac{\partial \bar{x}_1}{\partial x_1} &= \frac{\partial \bar{x}_4}{\partial x_4}, \\ \frac{\partial \bar{x}_1}{\partial x_4} &= \frac{\partial \bar{x}_4}{\partial x_1}, \end{aligned}\right\} \tag{26}$$

Thus we may arbitrarily choose $\bar{x}_1(x_1, x_4)$ to satisfy the equation

$$\frac{\partial^2 \bar{x}_1}{\partial x_1^2} - \frac{\partial^2 \bar{x}_1}{\partial x_4^2} = 0 \tag{26a}$$

and then (26) will determine the corresponding $\bar{x}_4$. Since e^γ is invariant under this transformation and also satisfies the wave equation, there exists a transformation where $\bar{x}_1$ is respectively equal or proportional to e^γ. In the *new* coördinate system we have

$$e^\gamma = a x_1$$

or

$$\gamma = \log a + \log x_1. \tag{27}$$

If we insert this expression for γ in (17)–(27) the equations reduce to the equivalent system

$$\beta_{11} - \beta_{44} + \frac{1}{x_1}\beta_1 = 0, \tag{28}$$

$$\alpha_1 = \tfrac{1}{2} x_1 (\beta_1^2 + \beta_4^2) - \frac{1}{2x_1}, \tag{29}$$

and

$$\alpha_4 = x_1 \beta_1 \beta_4. \tag{30}$$

Equation (28) is the equation for cylindrical waves in a three-dimensional space, if x_1 denotes the distance from the axis of rotation. The equations (29) and (30) determine, for given β, the function α up to an (arbitrary) additive constant, while, by (27), γ is already determined.

In order that the waves may be regarded as waves in a euclidean space these equations must be satisfied by the euclidean space when the field is independent of x_4. This field is represented by

$$A = 1; \qquad B = 1; \qquad C = x_1^2,$$

if we denote the angle about the axis of rotation by x_3. These relations correspond to

$$\alpha = 0, \qquad \beta = -\log x_1, \qquad \gamma = \log x_1,$$

and from this we see that the equations (27)–(30) are in fact satisfied.

We have still to investigate whether *stationary* waves exist, that is waves which are purely periodic in the time.

For β it is at once clear that such solutions exist. Although it is not essential, we shall now consider the case where the variation of β with time is sinusoidal. Here β has the form

$$\beta = X_0 + X_1 \sin \omega x_4 + X_2 \cos \omega x_4,$$

where X_0, X_1, X_2 are functions of x_1 alone. From (30) it then follows that α is periodic if and only if the integral

$$\int \beta_1 \beta_4 dx_4$$

taken over a whole number of periods vanishes.

In the case of a stationary oscillation, which is represented by

$$\beta = X_0 + X_1 \sin \omega x_4,$$

this condition is actually fulfilled since

$$\int \beta_1 \beta_4 dx_4 = \int (X_0' + X_1' \sin \omega x_4) \omega X_1 \cos \omega x_4 dx_4 = 0.$$

On the other hand, in the general case, which includes the case of progressive waves, we obtain for this integral the value

$$\tfrac{1}{2}(X_1 X_2' - X_2 X_1')\omega T,$$

where T is the interval of time over which the integral is taken. This does not vanish, in general. At distances x_1 from $x_1 = 0$ great compared with the wave-lengths, a progressive wave can be represented with good approximation in a domain containing many waves by

$$\beta = X_0 + a \sin \omega(x_4 - x_1),$$

where a is a constant (which, to be sure, is a substitute for a function depending weakly on x_1). In this case $X_1 = a \cos \omega x_1$, $X_2 = -a \sin \omega x_1$, so that the integral can be (approximately) represented by $-\frac{1}{2}a\omega^2 T$, and thus cannot vanish and always has the same sign. Progressive waves therefore produce a secular change in the metric.

This is related to the fact that the waves transport energy, which is bound up with a systematic change in time of a gravitating mass localized in the axis $x = 0$.

Note.—The second part of this paper was considerably altered by me after the departure of Mr. Rosen for Russia since we had originally interpreted our formula results erroneously. I wish to thank my colleague Professor Robertson for his friendly assistance in the clarification of the original error. I thank also Mr. Hoffmann for kind assistance in translation.

A. EINSTEIN.

IMPULSE CIRCUITS FOR OBTAINING A TIME SEPARATION BETWEEN THE APPEARANCE OF POTENTIAL AT DIFFERENT POINTS IN A SYSTEM.

BY

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University of Virginia.

The acceleration of ions to high speeds by impulsive methods requires an electrical circuit capable of transferring potential from electrode to electrode of the accelerating tube at the proper rate. To be of any practical value the circuit must be capable of operation with time delays between two successive points of the system as low as $2\text{–}3 \times 10^{-8}$ sec. and at voltages above 100 kv. This paper gives the results of an investigation of various methods which are suitable for this purpose. A number of these circuits may be used to advantage in other types of problems involving longer time intervals and lower voltages. While the theory underlying some of these experiments is well known, a part of it as well as most of the experimental results are new. It is hoped that a discussion of the possibilities and limitations of the various devices will be of general interest.

The methods have been divided into the following groups.

1. Transmission lines with continuously distributed constants, i.e., real transmission lines.
2. Transmission lines with constant lumped constants, i.e., artificial transmission lines.
3. Spark gap lines.
4. Discharge tube lines.

For ion acceleration these methods are used in two ways which differ considerably in their impulse characteristics. In the first the electrical circuit together with the tube electrode is initially at zero potential and is charged impulsively by connecting the input end to a supply condenser. This starts a charging wave which travels from electrode to electrode along

the system. The time delay in the building up of voltage at successive points is adjusted to correspond to the transit time of the ion between the two electrodes. This method has been used successfully for accelerating both ions and electrons.[1] In the second the electrical circuit and the electrodes are charged initially to a uniform constant potential. The voltage wave is then started by short circuiting the input end of the system. The potential in this case must be opposite in sign to that in the first. Electrons with speeds corresponding to 2.4×10^6 volts have been obtained [2] in this manner using a seven electrode tube with an applied potential of 700 kv.

For the charging method it is essential that the supply condenser have a low impedance since the steepness of the traveling voltage wave will be materially affected by any current limitation in the supply circuit. At high voltages this condition is difficult to obtain.

The discharging method avoids this difficulty since the steepness of the wave front is determined only by the constants of the transmission circuit and the rapidity of short circuiting at the input end. It has the disadvantage that the entire system must be capable of withstanding a high static potential. This requires much better insulation and shielding than is necessary in the first case where the tube is only required to withstand impulsive voltages of relatively short duration.

In all this work spark gaps are used for switching and short circuiting between points of the circuit. To prevent appreciable distortion of the wave front the switching operation must be completed as rapidly as possible. The total time involved should be smaller, certainly not greater than that of the time delay ($2\text{–}3 \times 10^{-8}$ sec.)

For a 1 cm. spark gap in air (2.54 cm. brass spheres) the potential falls to 1/3 value [3] in approximately 2×10^{-8} sec. It was found by means of a high speed cathode ray oscillograph that this time is increased with the wide spacings and large spheres necessary for high voltages. To reduce this time a

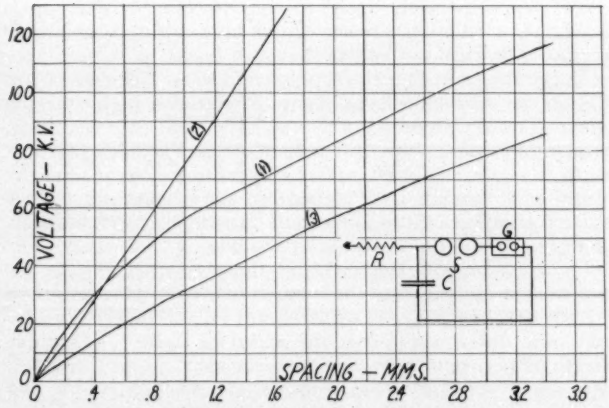
[1] Beams and Snoddy, *Phys. Rev.*, **44**, 784 (1933). Beams and Ham, *Phys. Rev.*, **45**, 746 (1934). Beams and Trotter, *Phys. Rev.*, **45**, 849 (1934).

[2] Beams and Trotter (unpublished).

[3] Street and Beams, *Phys. Rev.*, **38**, 416 (1931).

second gap G is placed in series with the first as shown in Fig. 1. This gap can be either a vacuum gap, a gap under oil or a gap in dry, filtered air. Curves of breakdown versus spacing for impulsive voltages are shown in Fig. 1 for these three types. (1) A vacuum gap with pure copper electrodes (2.54 cm. diameter) under excellent vacuum conditions. Since the breakdown voltage in a vacuum gap depends upon the condition of the electrode surface, the length of the impulse and the maximum current was kept approximately constant at all voltages.

FIG. 1.



Spark gap breakdown versus spacing for impulsive voltages applied to 2.54 cm. diameter spheres. Curve 1, vacuum gap with pure copper electrodes. Curve 2, steel spheres in transformer oil No. 10 C. Curve 3, steel spheres in dry filtered air.

(2) A gap with steel spheres (2.54 cm.) in Transil Oil No. 10C. (3) A steel sphere gap (2.54 cm.) enclosed in a glass cylinder containing air at atmospheric pressure which had been carefully dried and filtered.

From these curves it is seen that it is possible to use gaps of this kind at small spacings for high impulsive potentials. The rate of potential fall observed with the oscillograph is considerably greater than in an ordinary gap at wide spacings. The approximate times to 1/3 value for the three gaps are

$1-1.5 \times 10^{-8}$ sec. for a vacuum gap at 100 kv., 2×10^{-8} sec. for the overvolted air gap at 120 kv., and $2-2.5 \times 10^{-8}$ sec. for the oil gap at 200 kv. For the purpose of estimating the influence of this breakdown upon the shape of the wave front, the rate of potential fall is assumed to be exponential and in some cases linear.

1. REAL TRANSMISSION LINES.

The lines used were either of the simple two wire type or the single wire with return through a large grounded metal sheet on the floor. Since the speed of propagation of the impulse is approximately equal to that of light, this group is useful only with relatively short time intervals. A schematic diagram of typical systems is shown in Fig. 2 (*a*, *b*, *c*).

In this diagram C_s is the supply condenser, S the spark gap in air, G the overvolted type of gap, R relatively high charging resistances and C_e represents the capacity of the tube electrode. Since the lines are short, the resistance and leakage per unit length may be neglected without appreciable error and the transmission circuit itself taken as non-dissipative. C_s is assumed large enough to maintain a practically constant voltage during the initial charging of the line.

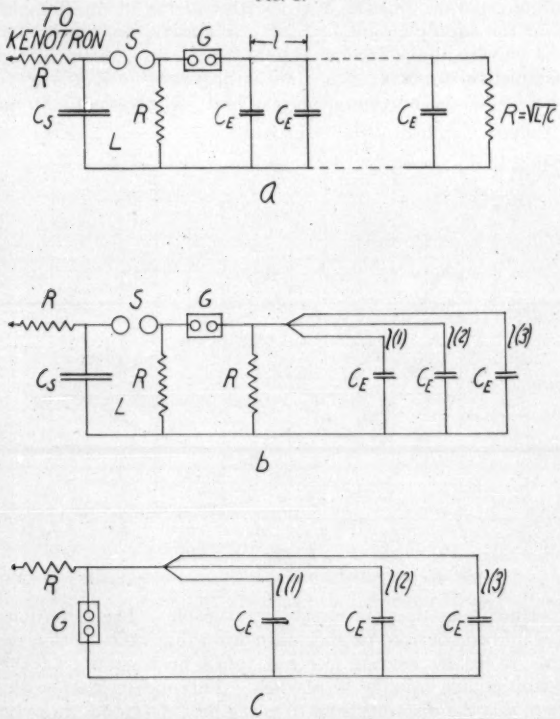
Figure 2 (*a*) the electrodes of the accelerating tube are connected in succession to the same simple line. The length of wire between electrodes is adjusted until l/v is equal to the desired time delay where v is the speed of light. To reduce reflections to a minimum, the output end is closed through a resistance $R = \sqrt{L/C}$ where L and C are the inductance and capacity per unit of length of the line. The correct value is easily determined by measuring the voltage at the output end with a spark gap or an oscillograph as a function of R. When the maximum voltage across R is equal to the input voltage V, the resistance is sufficiently near to the correct value for all practical purposes.

In Fig. 2 (*b*) a separate line goes to each electrode. The lines are joined together as near as possible to the gap G. The time delays are determined by the differences in wire lengths.

Figure 2 (*c*) is identical with (*b*) except that the lines and electrodes are charged initially and the wave produced by the breakdown of G. Provided the total capacity of this system

is not too great, it can be charged impulsively through R from an auxiliary condenser circuit until the breakdown voltage of G is reached. In this way higher potentials can be used with

FIG. 2.



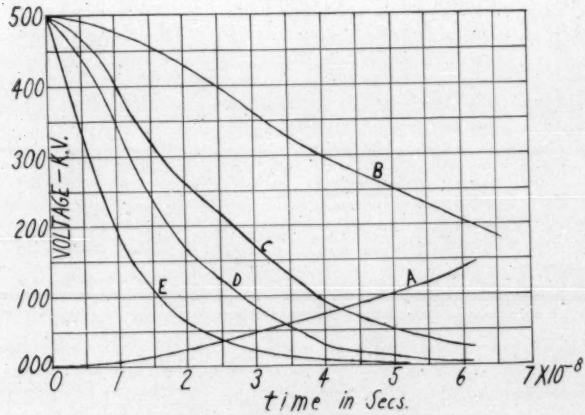
Three types of real transmission lines used for the acceleration of particles.

the same insulation than could be done if the charging process is slow. It also enables an overvolted gap to be used at G which could not be done with a slow charging rate.

The wave front obtained in these three cases is dependent

on the rate of fall of potential in G, the impedance of the supply circuit and the impedance of the transmission system observed from the input end. Since only the wave front is of importance, the impedance of a single line can be taken as $R = \sqrt{L/C}$ and of n parallel lines as R/n. With C, large the inductance, L, of the supply circuit becomes the current limiting factor. The voltage applied to the system by the breakdown of G is assumed as a function of the time in the form $V = E(1 - e^{-\delta t})$, where E is the maximum voltage and δ is chosen to fit the

FIG. 3.



Voltage at input end of the real transmission lines with respect to time.

experimental values as closely as possible. The equations have all been derived on the assumption that no reflection returns from the nearest electrode until at least 2/3 of the maximum line voltage is reached. This means that $2\,d/v$, where d is the distance from G to the first electrode, must be greater than the time length of 2/3 the wave front.

The line voltage as a function of time at the input end for Fig. 2, a and b, is given by

$$V(t) = E\delta\left[\frac{1}{\delta}(1 - e^{-\delta t}) + \left(\frac{e^{-\delta t} - e^{-Z/L\,t}}{\delta - Z/L}\right)\right], \qquad (1)$$

where Z, i.e. R/n is the surge impedance of the transmission system and L is the inductance of the charging system. n equals the number of separate lines attached to G. For Fig. 2 (a) $n = 1$, and for Figs. 2 (b and c) $n = 3$. Equation (1) also serves for Fig. 2 (c) when the inductance L is replaced by that of the connecting wires of gap G.

Curves of typical wave fronts are shown in Fig. 3 and the values of the constants in Table I. The curves clearly illus-

TABLE I.

Curve.	Type of Gap.	Inductance L in henries.	Surge Impedance Z in ohms.
A Charging 7 lines	Air Gap $\delta = 2.2 \times 10^7$	4.5×10^{-6}	60
B Discharging 7 lines	Air Gap $\delta = 2.2 \times 10^7$	1×10^{-6}	60
C Discharging 7 lines	Vacuum Gap $\delta = 1.1 \times 10^8$	1×10^{-6}	60
D Discharging 7 lines	Vacuum Gap $\delta = 1.1 \times 10^8$	0.5×10^{-6}	60
E Discharging 1 line	Vacuum Gap $\delta = 1.1 \times 10^8$	0.5×10^{-6}	450

trate the effect of the inductance L in slowing up the wave front and thus emphasize the great advantage obtained by the discharging type of line where the inductance can be reduced to a minimum value. The steepness of the wave front is also effected by the rate of breakdown of the spark gap used in the line. Thus, the difference in the rate of potential fall in curves B and C is due solely to the faster breakdown of the vacuum gap as contrasted with the non-overvolted air gap. Curves C and D illustrate the effect of reducing the inductance L. Curve A shows how the large inductance of the charging system effects the wave front in charging up the multiple line. It should be remembered that the surge impedance Z of a multiple wire circuit becomes very low (Z/n) and hence makes

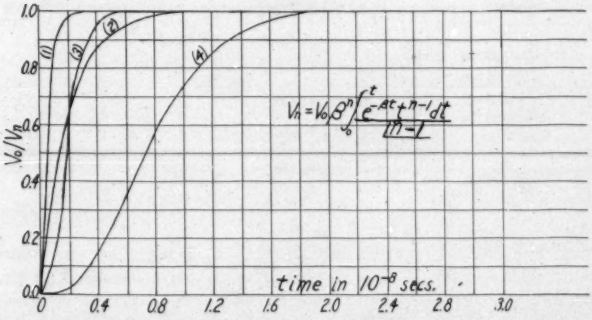
it unsuitable for a charging system. Curve E shows the wave front for a single line (as in Fig. 2 a) for the discharge case. Due to the higher surge impedance the potential falls more rapidly than in the multiple wire circuit.

The wave distortion produced by the loading of the line with the electrode capacities in Fig. 2 (a) is easily determined neglecting as before the effect of reflections between electrodes. With a perpendicular voltage, V_0, applied at the input end, the variation of voltage at the nth electrode as a function of time is given by [4]

$$V_n = V_0 \beta^n \int_0^t \frac{\epsilon^{-\beta t} t^{n-1}}{\lfloor n-1} dt \qquad (2)$$

where $\beta = 2/ZC_e$. Curves for the wave front at the 1st and 4th electrodes are shown in Fig. 4 with $C_e = 1 \times 10^{-11}$ farads

FIG. 4.



Wave fronts at the 1st and 4th electrodes of a loaded real transmission line. Curve 1 is the 1st electrode with C 1×10^{-11} farads. Curve 2 is for the 4th electrode with the same capacity. Curve 3 is the 1st electrode with C 4×10^{-11} farads and Curve 4 is for the 4th electrode with the same capacity.

(curves 1 and 2) and $C_e = 4 \times 10^{-11}$ farads (curves 3 and 4). Z is taken as 100 ohms. Time is measured from the moment of arrival of the incident wave.

With the potential at the input end of the lines in Fig. 2,

[4] For general methods of derivation, see J. R. Carson, "Electric Circuit Theory and Operational Calculus," McGraw-Hill, p. 132.

b, c given by $V = V_0(1 - \epsilon^{-\delta t})$ the terminal voltage across any one of the capacities C_e is given by:

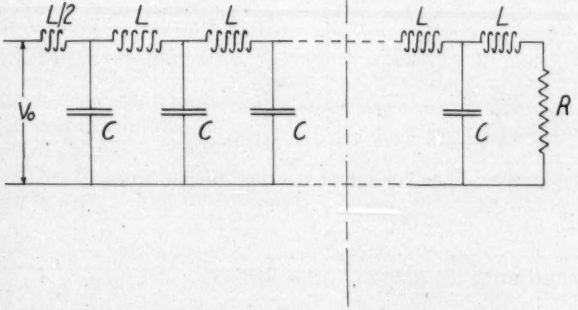
$$V = V_0\left[2 + \left(\frac{\delta ZC_e + 1}{\delta ZC_e - 1} - 1\right)e^{-\delta t} - \frac{2\delta ZC_e}{\delta ZC_e - 1}e^{-t/ZC_e}\right]. \quad (3)$$

For small values of capacity ($1\text{–}2 \times 10^{-11}$ farads) the distortion is not noticeable and equation (3) reduces to $2V_0(1 - e^{-\delta t})$. The line is practically open circuited and it is seen that the voltage will be doubled by reflection. This fact must be taken into account in the computation of electrode sizes and separations.

2. ARTIFICIAL TRANSMISSION LINES.

A low pass filter line with series inductance and shunt capacity was used in this work. A schematic diagram is given in Fig. 5. For ion acceleration the tube electrodes are con-

FIG. 5.



An artificial transmission line with series inductance and shunt capacity.

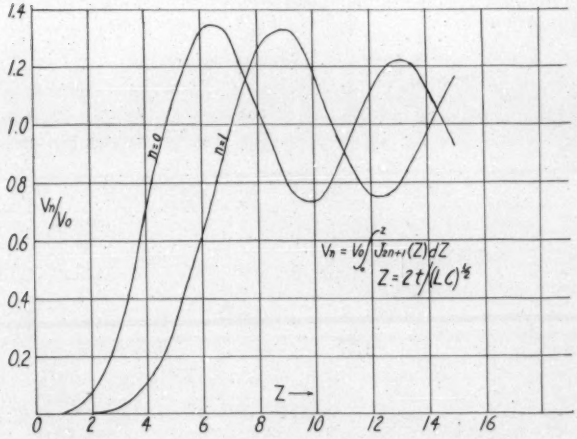
nected to the capacities C. With a constant voltage V_0 impressed at mid-series position of the oth section ($n = 0$),

the current in the nth section is given by [5]

$$i_n = V_0\sqrt{\frac{C}{L}}\int_0^{\lambda t} J_{2n}(z)dz, \qquad (4)$$

where $\lambda = 2/\sqrt{LC}$ and $z = 2t/\sqrt{LC}$ and J_{2n} is the Bessel function of order $2n$ and argument z. This assumes the line to contain an infinite number of sections or to be terminated by an impedance which prevents reflection and to be non-

FIG. 6.



Voltages on the 0th and 1st sections of the artificial line for unit applied voltage.

dissipative. The voltage across the nth capacity is

$$V_n = V_0\int_0^t \frac{i_n - i_{n+1}}{C}dt.$$

Substituting for i_n and i_{n+1} this becomes

$$V_n = V_0\int_0^{\lambda t} J_{2n+1}(z)dz. \qquad (5)$$

Curves of applied voltage with $V_0 = 1$ are shown in Fig. 6

[5] See J. R. Carson, "Electrical Circuit Theory," p. 117.

for $n = 0, 1$. At a time approximately equal to $2n/\lambda$, measured from the moment the input voltage is applied, the condenser voltage, Vn, starts to increase rapidly. This line consequently serves as a system for transmitting voltage at a finite speed of $1/\sqrt{LC}$ sections per second. It is evident from equation (5) that this velocity is only apparent since Vn has a finite though small value for any time $t > 0$. The derivation of these equations assumes an idealized system in which there is no space factor. The actual construction of an experimental line in which the $\sqrt{LC}$ i.e., the time delay per section is small (2×10^{-8} sec.) must be carried out with some care. The necessary condition is evidently that $\frac{d}{v} \ll \sqrt{CL}$ where d is the electrical path between sections and v the speed of light. The capacitive and inductive coupling between adjacent sections is found to be of slight practical importance.

The voltage difference between successive sections, which is important for ion acceleration, is given by

$$V_n - V_{n+1} = L\frac{di_{n+1}}{dt}$$

or

$$V_n - V_{n+1} = 2J_{2n+2}(\lambda t). \tag{6}$$

Curves of this difference are shown in Fig. 7 for $n = 0, 1, 2, 3$ and in Fig. 8 for $n = 10$ and 20. The applied voltage is unity. In the design of a tube to be used with this transmission system the electrode lengths and separations must be fitted to these curves.

The actual computation of i_n and V_n is easily carried out for any particular case. Since

$$i_n = C\frac{dV_n}{dt} + C\frac{dV_{n+1}}{dt} + \cdots + C\frac{dV_{n+q}}{dt} + i_{(n+q+1)},$$

i_n by (5) can be written in the form

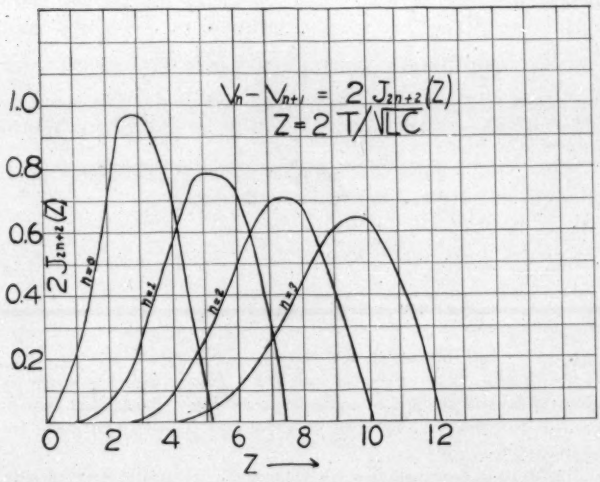
$$i_n = \sqrt{\frac{C}{L}}\, 2 \sum_{q=0}^{q} J_{2n+2q+1}(\lambda t) + i_{(n+q+1)}. \tag{7}$$

By repeated use of (6) it is found that

$$V_n = 2 \sum_{q=1}^{q} J_{2n+2q}(\lambda t) + V_{(n+q)}.$$

If q is made sufficiently large, $i_{(n+q+1)}$ and $V_{(n+q)}$ will then be insignificant during the time for which the curves are wanted, and the values of i_n and V_n can be obtained directly from Bessel function tables.[6]

FIG. 7.



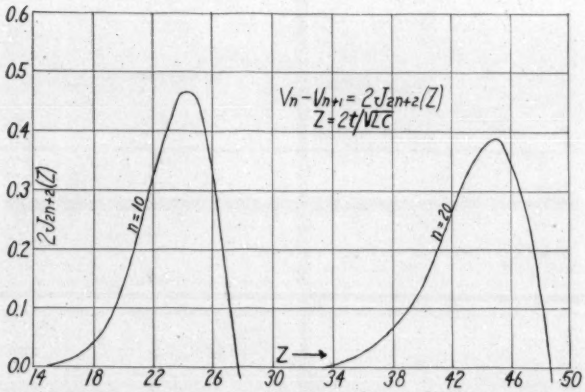
Voltage difference between the first four sections for the artificial line with unit applied voltage.

If the inductances in a line of this type are replaced by a straight connecting wire, the system becomes a real transmission line loaded at closely spaced intervals. Since d/v, where d is again the wire length between sections, can be made quite small there are a great many reflections between parts of the circuit before the voltage wave reaches its maxi-

[6] Tables of Functions by Jahnke and Emde; B. G. Teubner, Leipzig.

mum value. The behavior of this line is approximated by an ideal artificial line with lumped inductances equivalent to the inductance of the loop formed by two of the condensers with their connecting wires. In the actual construction of an artificial line for use with time delays of $2\text{–}3 \times 10^{-8}$ sec. the lumped inductance L is relatively small ($1\text{–}3 \times 10^{-6}$). Allowance must consequently be made for the influence of the loop inductance when the coils, L, are made. Oscillograms of wave forms on an artificial line with 15 sections are shown in

FIG. 8.



Voltage difference between 10th and 11th sections and between 20th and 21st sections for the artificial line with unit applied voltage.

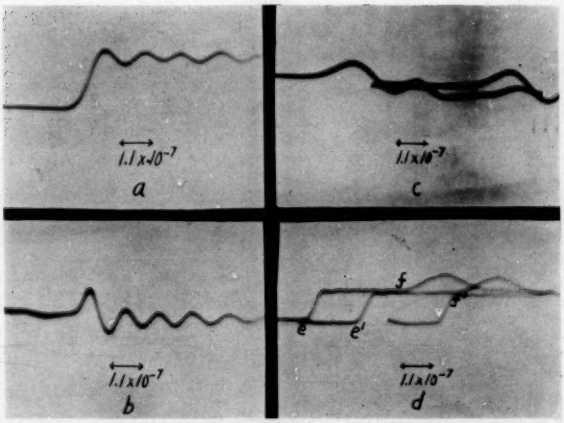
Fig. 9. The time per section is 4.31×10^{-8} sec. with $C = 830 \times 10^{-12}$ farads and $L = 2.4 \times 10^{-6}$ henries. The line was charged initially and discharged by a special gap at the point V_0 in Fig. 5. The resistance R was omitted. Fig. 9 (*a*) is the voltage wave at the 2d section; (*b*) and (*c*) are the voltage differences between the 2d and 3d and between the 10th and 11th sections respectively.

For Fig. 9 (*d*) the lumped inductances were replaced by a straight connecting wire making a real line loaded at intervals of approximately 40 cms. with the same capacities as above

(830×10^{-12} farads). The initial wave at the 2d section is shown at e and the reflected wave from the open circuited end at f. The time from e to f as measured on the oscillogram is 40×10^{-8} sec. while that computed on the assumption that the time per section is $\sqrt{LC}$ where L is the loop inductance and C the lumped capacity is 42×10^{-8} sec.

The maximum current is approximately $1.47 V_0 \sqrt{C/L}$. A lower limit to C is set by the condition that its value should

FIG. 9.



Oscillograms of wave forms on an artificial line with 15 sections. (*a*) Voltage wave at the 20th section. (*b*) and (*c*) Voltage differences between the 2d and 3d and between the 10th and 11th sections respectively. (*d*) A real line loaded at 40 cm. intervals where the initial voltage on the 2d section is shown at e and the reflected wave from the open end at f.

not be appreciably affected by any change in the position of connecting wires or surrounding objects. For a definite time between sections this determines L. The $\sqrt{C/L}$ can consequently not be decreased indefinitely. For high voltages the input current will be quite large. This means that the supply circuit, if the line is to be charged, or the short circuiting gap system if the line is to be discharged, must be of low impedance if an undistorted wave is to be obtained.

V. 19

To illustrate the effect of adding inductance in series with the input end of the line shown in Fig. 5, computations were made for current and voltage when a potential V_0 is applied with $L/2$ replaced by L. The current, voltage and voltage difference for the nth section are given by the following equations,

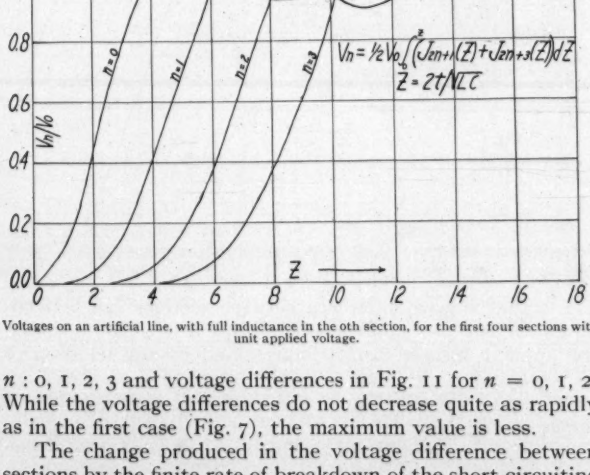
$$i_n = V_0\sqrt{C/L}(2n+1)\int_0^{\lambda t}\frac{J_{2n+1}(z)}{z}dz, \tag{8}$$

$$V_n = \frac{V_0}{2}\int_0^{\lambda t}(J_{2n+1}(z) + J_{2n+3}(z))dz, \tag{9}$$

$$V_n - V_{n+1} = J_{2n+2}(\lambda t) + J_{2n+4}(\lambda t). \tag{10}$$

Curves of voltage as a function of z are illustrated in Fig. 10 for

FIG. 10.



Voltages on an artificial line, with full inductance in the oth section, for the first four sections with unit applied voltage.

n : 0, 1, 2, 3 and voltage differences in Fig. 11 for n = 0, 1, 2. While the voltage differences do not decrease quite as rapidly as in the first case (Fig. 7), the maximum value is less.

The change produced in the voltage difference between sections by the finite rate of breakdown of the short circuiting

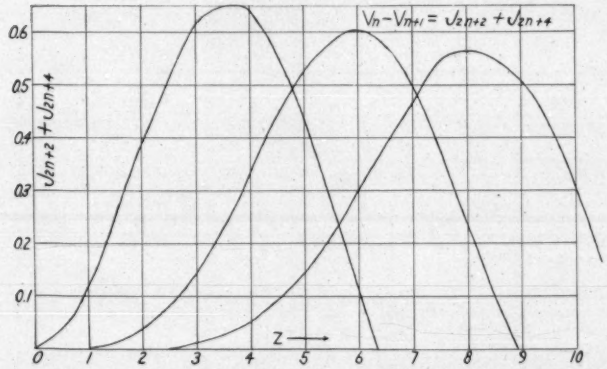
gap in the circuit of Fig. 5 (R-omitted) can be simply determined if the applied potential is assumed to be linear, i.e., $V_0 = at$. Denoting the difference for unit potential applied at $t = 0$ by $V_d = 2J_{2n+2}(\lambda t)$ the result is determined by the equation

$$V_n - V_{n+1} = \int_0^t V_d'(x)\, V_0(t - x)dx.$$

Introducing the values of V_d' and $V_0(t - x)$ this becomes

$$V_n - V_{n+1} = a\sqrt{LC}\int_0^{\lambda t} J_{2n+2}(z)dz. \qquad (11)$$

FIG. 11.



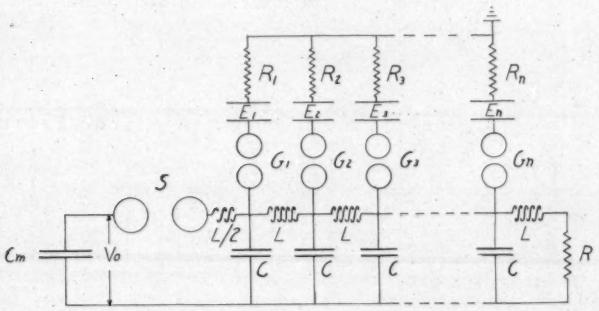
Voltage differences for the first three sections where unit voltage is applied to the artificial line with full inductance in the oth section.

The actual voltage difference between sections can be computed for any particular case from this if it is assumed that the applied voltage can be represented by the addition of $V_0 = at$ and $V_0 = -at'$ with the origin of t' displaced by an amount corresponding to the total time of breakdown of the switching gap.

There are a number of modifications in the artificial line system which are of interest and which improve the voltage

efficiency. Before describing them a word of caution should be included. The artificial line is at best a complicated structure and considerable care is necessary in its construction if its transient performance is to follow the theoretical predictions. Any modifications or alterations introduced into its regular structure are apt to have a profound influence upon its operating characteristics. For this reason it is always necessary to determine the voltages and voltage differences in these modified systems by quantitative measurement with a cathode ray oscillograph before any attempt is made to use them for any purpose.

FIG. 12.



An artificial line where the voltage is applied to the electrodes by means of spark gaps.

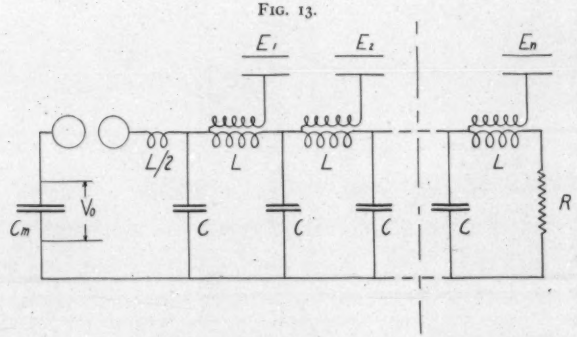
The most useful addition to an artificial line is made by adding spark gaps between the line capacities C of Fig. 5 and the electrodes which are connected to them as shown in Fig. 12. High resistance leaks to ground R_1, $R_2 \cdots R_n$ are connected to each electrode. These spark gaps are set at such a value that breakdown occurs near the peak of the voltage wave for each section. In this way the voltage difference is increased. The only potential which appears at the electrode before breakdown of this series gap is that due to capacity coupling and this can usually be made a fairly small percentage of the line capacity voltage. The action of this system can readily be determined by an analysis of the

curves for V_n (Fig. 6). For consistent performance the series gaps should be made of photo-sensitive material and intensely irradiated by ultra-violet light.

If it is desired to obtain an output voltage higher than that applied, the inductances L may be constructed with a secondary winding and operated as air core transformers as shown in Fig. 13. The capacity between windings prevents any great increase in voltage when such steep wave fronts are used, but a multiplication of 2 is certainly possible.

In the actual acceleration of ions the speed of the ion is increasing as it traverses the tube. This is usually allowed

FIG. 13.



An artificial line with transformer step up at each electrode.

for by an increase in electrode length keeping the time interval constant. It is also possible to taper the constants in the artificial line so that electrode lengths are kept constant and the time interval changed.

A mechanical model of such a line was constructed with tapered inductances and constant capacity. It was found that the time interval between sections decreased as the inductance was decreased and that the steepness of the wave front was maintained more nearly constant.

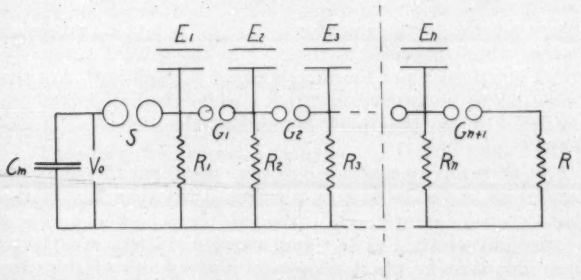
The artificial transmission line may also be used in a variety of ways to "Master" a series of discharges. For example the series of successive electrodes of the ion accelera-

tion tube may be charged to a high voltage with respect to ground through high resistances by any type of charging system such as a kenetron and transformer or Marx impulse generator. Each of the successive electrodes may then be discharged through a three electrode spark gap in which the center electrodes are attached by appropriate resistances to the various successive sections of an artificial transmission line. In this way the time interval between the successive discharges of the tube electrodes is determined by the constants of the artificial transmission line.

3. THE SPARK GAP LINE.

In order to reduce the time between the application of the potential to the successive electrodes to as small a value as

FIG. 14.



A spark gap transmission line.

possible and still keep the applied wave front steep, a so-called spark gap line was devised. It is well known that a spark gap can be overvolted for a short time before it breaks down. This time may be made of the order of 10^{-8} sec. in special cases. Also it has been shown that with highly overvolted spark gaps the rate of fall of potential is very great.[3, 7] Fig. 14 shows a schematic diagram of the line. The spark gaps G_1 and G_n are connected directly to the electrodes E_1 to E_n respectively of the tube in which the ions are accelerated. To prevent them from floating, the electrodes are grounded

[7] Flowers, *Phys. Rev.*, **48**, 954, 1935.

through the 100,000 Ω resistances R_1 to R_n. The resistance R across the end of the line prevents reflection.

The impulse is applied to the line by the discharge of S. Since the capacities of the electrodes and spark gaps to ground are of the same order of magnitude as their intercapacities, the potential across G_1 is much higher (several times in our case) than across G_2 or G_3, etc. As a result G_1 breaks down, first followed by G_2, $G_3 \cdots G_{n+1}$ in succession. Since these capacities to ground C_1 and the intercapacities C_2 are known, the potential applied to the successive electrodes can be quite accurately determined. For example, if V is the applied potential, the potential V_k across G_k is given by

$$V_k = V\left(\frac{C_1}{C_1 + \frac{C_2}{2} + \left(\frac{C_2^2}{2} + C_1C_2\right)^{1/2}}\right)^k.$$

Therefore this arrangement serves as a type of transmission line in which the natural time lag in the breakdown of the spark gap determines the time between the application of the potential to successive electrodes while the rate of fall of potential across the spark determines the steepness of the wave front.

At first unprotected air gaps were used, but the changing conditions of the laboratory air caused the time lags of the gap to become erratic. To avoid this the gaps were enclosed in carefully cleaned glass tubes whose diameters were large in comparison to the diameters of the spheres of the gap. The air was carefully filtered, dried, and the ions removed by auxiliary fields so that the gaps could be highly overvolted in a manner previously described [3, 7] and advantage taken of the resulting steep wave fronts produced. With this arrangement it was possible to impress a voltage 10 times the static breakdown voltage across the gap for approximately 10^{-8} sec. before the potential started falling. Also the oscillograms showed that the potential across the gap fell to one-third its original value in a little over 10^{-8} sec. However, the spark gaps started to become somewhat erratic when the distance between the spheres of the gap exceeded 2 or 3 mm., which limited the usefulness of the line for our purpose to applied potentials not greater than 60,000 volts.

In the above arrangement considerable care must be taken to carefully filter and dry the air as well as keep it as free as possible of ions if the spark gaps are to function satisfactorily. However, it was found that all this trouble could be avoided if a few drops of carbon tetrachloride were put inside the spark gap chamber. With steel electrodes the gaps could easily be overvolted 10 times giving very steep wave fronts. Unfortunately, these gaps also became too erratic for our purpose for voltages over 60 or 70 K.V. The spark gaps were next surrounded by Transil oil No. 10. It was found that the oil gaps could be made to function satisfactorily up to applied potentials of 100 K.V. However, at 250 K.V. applied potential, the time lags became too variable for our purpose and 2.5×10^{-8} sec. were required for the potential to fall to 1/3 of its value. While the above types of spark gap lines can be made to operate successfully for voltages under 60 K.V., giving dependable time intervals of, roughly, the order of 2 to 2.5×10^{-8} sec. as well as very steep wave fronts, we abandoned them for our immediate purpose because of the voltage limitation.

4. THE DISCHARGE TUBE LINE.

It has long been known [8] that when an impulsive potential is applied to the ends of a long discharge tube that the luminosity starts at one end and progresses toward the other. When care is taken to maintain one end at ground while an impulsive voltage is applied to the other end, the luminosity progresses from the high voltage electrode to the grounded electrode regardless of the sign of the impressed voltage.[9] By means of the high speed cathode ray oscillograph we have found that the voltage wave also traverses the discharge tube from the high voltage electrode to the grounded electrode with a definite velocity. The velocity of the voltage wave can be varied over wide ranges as it depends upon the pressure of the gas and to some extent upon the applied voltage. When the applied voltage exceeds 100 K.V. and the pressure is properly adjusted there is no measurable attenuation or flattening of the wave front in a 10 meter tube.

[8] J. J. Thomson, "Recent Researches," 115, 1893.

[9] Beams, *Phys. Rev.*, **36**, 997, 1930.

With a 5 mm. tube filled with air at .08 mm. Hg pressure a positive 127 K.V. wave traversed the tube with a speed of 9×10^8 cm./sec., while with the same applied voltage wave but with a pressure of 5.4 mm. Hg the wave traveled with a speed of 4.3×10^9 cm./sec. The current carried by the wave itself reached several hundred amperes while the maximum current in the tube during the discharge reached several thousand amperes. A detailed description of the action of this discharge tube line will be given later as it is still under investigation. However, we believe that there is little doubt that it will be of use for many problems, especially in the acceleration of ions to very high velocities.

We wish gratefully to acknowledge a grant from the Penrose Fund of the American Philosophical Society which made this work possible.

V.
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THE VISIBILITY OF VARIOUS TYPE FACES.

BY

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Although the vast majority of human beings begins life with unimpaired vision, a very large percentage has measurably defective vision at the age of fifty. Certainly it is possible that many of these changes result from the use and abuse of the visual mechanism in performing unnaturally severe and exacting near-vision tasks for prolonged periods. In fact, much evidence points toward such a conclusion. Severe and critical visual tasks are imposed by civilization, but they may be made easier through (1) the correction of ocular deficiencies, (2) the provision of adequate light and proper lighting and (3) by increasing the visibility of objects to be seen when this is possible. The present discussion pertains largely to the third of these controllable phases of ocular hygiene. Since reading is a universal visual task in the home, schoolroom, and office, the visibility of the reading matter is of major importance.

Obviously, the task of reading may be made easier by increasing type size within certain limits.[1, 4] However, the improvement in visibility which is possible through the use of larger type is usually limited by economic factors as well as practical considerations involving the convenience of certain page-sizes or number of pages in a given volume. In addition, the advantage derivable from larger type sizes is probably limited due to the increase in ocular muscular effort required in reading as the size of the type is increased. Furthermore, perceptual anomalies may be introduced by decreasing the number of letters included in a single perceptual span.[2] In general, an acceptable standard of type size has been more or less definitely indicated by the characteristics of good typography since these have been evolved through mass experience for generations.[3] Hence the fact that text-matter in a book or magazine is seldom, if ever, printed in larger than 12-point

type may be considered as an indication that 12-point type represents a practical maximum in type size. Obviously, this conclusion does not pertain to books prepared for sight-saving classes in schools.[4]

The degree of visibility, for a given type size, is also a function of the pattern or configuration of the type face; but deficiencies in visibility due to design are obviously unjustifiable since the factor of cost is not involved. This conclusion is particularly significant in cases where small types of relatively low visibilities are used, as is frequently the case. In Table I are presented the relative visibilities of a series of twenty different 8-point type faces as determined with the Luckiesh-Moss Visibility Meter.[5]

It is emphasized that the values presented in Table I relate only to the visibility of the printed characters and not to their respective "attention" values. For example, it will be noted that the Caslon Light Italic is less visible than the Caslon Light although it is obvious that a few words printed in the italics and inserted in a body of the latter would possess considerable attention value. It will also be obvious that the visibility method of appraising type faces does not include æsthetic considerations of the appearance of the printed matter. However, visibility is generally of major importance and is the predominant factor in exacting penalties in eye-strain, eye-fatigue, nervous tension, wasted energy and other effects upon the human seeing-machine.

The data in Table I possess a high degree of reliability, from the statistical viewpoint, since their corresponding probable errors are of the order of magnitude of 1.5 per cent. In computing these probable errors the systematic differences among observers were eliminated. The significance of the differences in visibility of the various type faces is indicated by comparing these data with their corresponding probable errors. For example, the difference between Bodoni Book and Bodoni Bold is statistically real since it is approximately seven times as great as the probable error of the difference. On the other hand, since the difference in visibility between Caslon Light and Sans Serif Light is of the same order of magnitude as the probable error of the difference, these two type faces may be regarded as approximately equal in visibility.

TABLE I.

THE RELATIVE VISIBILITY OF VARIOUS 8-POINT MACHINE SET MONOTYPES*

These data were obtained with the Luckiesh-Moss Visibility Meter and represent the averages of 5 series of 5 measurements each made by 5 different observers, experienced in the use of the instrument. Each style of type was well-printed with black ink upon a good grade of non-glossy white paper. The latter was illuminated to 10 footcandles in all cases. The measurements of visibility pertain to the lower case letters. (The names of the various type faces are actually printed in the type face designated. This caption is printed in 8-point Bodoni Book Monotype.)

Type Face (8-point)	Relative Visibility	Per Cent Prob. Error	Per Cent Visibility	For Equal Visibility Size in Points	For Equal Visibility Footcandles Required
Bodoni Book	3.65	1.0	100.0	8.0	20
Bodoni Book Italic	*3.50*	*1.2*	*96.0*	*8.3*	22
Bodoni Bold	**3.95**	**1.3**	**108.3**	**7.4**	**17**
Caslon Light	3.51	1.2	96.2	8.3	22
Caslon Light Italic	*2.96*	*0.7*	*81.1*	*9.4*	*36*
Caslon Bold	**3.89**	**0.8**	**106.5**	**7.5**	**17**
Sans Serif Light	3.54	0.9	97.1	8.2	22
Sans Serif Medium	3.86	1.1	105.7	7.6	17
Sans Serif Bold	**3.81**	**0.7**	**104.3**	**7.7**	**18**
Cheltenham Wide	3.67	1.2	100.5	8.0	20
Cheltenham Bold	**3.96**	**1.2**	**108.5**	**7.4**	**17**
Cheltenham Bold Condensed	**3.40**	**1.4**	**93.2**	**8.5**	**25**
LIGHT COPPER-PLATE GOTHIC**	3.58	1.0	98.1	8.1	21
HEAVY COPPER-PLATE GOTHIC**	3.74	1.2	102.5	7.8	19
Goudy Light	3.43	1.3	94.0	8.4	24
Goudy Antique	3.88	1.7	106.2	7.5	17
Goudy Bold	3.82	1.5	104.8	7.7	18
Cochin Light	3.73	1.5	102.3	7.8	19
Cochin Bold	**4.12**	**1.4**	**112.6**	**7.1**	**15**
Garamond Bold	**4.33**	**1.5**	**118.7**	**6.6**	**14**

* From same manufacturer.

** Equivalent in size to 8-point Bodoni Book type.

The values of visibility presented in the second column of Table I are based upon a scale derived from the visibilities of a series of test-objects of simple geometrical form described in detail elsehwere.[5] Such a scale possesses significance in an absolute sense in that unity on the scale represents the smallest object of maximal contrast which may be recognized by subjects possessing average normal vision. A scale value of "2" indicates that the object of regard is equivalent in visibility to a standard test-object, under the standard conditions, which is twice as large as the minimum visible object. Hence these values of visibility may be regarded as "factors of safety" applicable to various visual situations. If the data are interpreted from this basis, it will be noted that the visual factors of safety vary from 2.96 to 4.33 for the least and most visible type faces, respectively.

The differences in visibility among the various type faces may also be expressed in terms of *type size* of a particular type face. Thus the comparisons may be expressed in *points* * of type size rather than in *minutes visual angle* of an arbitrary test-object of a simple geometric pattern. Bodoni Book Monotype was selected as a basis for such comparisons by reason of its wide usage in typography. This relationship is given in the fifth column of Table I. The interpretation of these data is illustrated by the following samples:

1. The maximum difference in visibility among the various type faces of Table I is obtained for Caslon Light Italic and Garamond Bold and is equivalent to 2.8 points in type size on the scale developed for the Bodoni Book Monotype. Obviously, a difference in visibility equivalent to nearly 3 points between two so-called 8-point types is an important one.

2. The difference between Caslon Light Italic and Bodoni Italic is 0.54 in relative visibility of slightly more than one point in equivalent type size. Thus it is possible to gain the attention value of italics without a serious loss in visibility as in the case of Bodoni type.

3. The increase in visibility gained by the use of bold-face rather than light-face Cochin type is about three-fourths of a point. Approximately the same relationship is obtained for the Caslon and Goudy type faces. However, it will be noted that

* The value of the point is 0.0138 inch, or nearly 1/72 inch.

Sans Serif Bold is somewhat less visible than the Sans Serif Medium; and that Heavy Copperplate Gothic is only slightly more visible than Light Copperplate Gothic.

Since illumination is a fundamental variable of the visual threshold, it is obvious that the differences in visibility among various type faces may also be expressed in terms of this variable. The values given in the sixth column of Table I were computed from the visibility ratings of the various type faces and the relationship between visibility and intensity of illumination for 8-point Bodoni Book Monotype. These values are based upon the assumption that 20 foot-candles upon 8-point Bodoni Book Monotype is acceptable from the standpoint of providing a reasonable degree of ease in reading. It will be noted from Table I, for example, Caslon Light Italic illuminated to 36 footcandles is equivalent in visibility to Garamond Bold illuminated to only 14 footcandles. In general, it may be concluded that the variations in visibility, expressed in terms of illumination, are quite significant in many cases.

In Table II are shown the intensities of illumination (footcandles) of glareless lighting necessary to make four sizes of type (6, 8, 10, and 12-point Bodoni Book Monotype, respectively) of equal visibility.

TABLE II.

Each intensity of illumination presented represents the mean of 90 observations obtained from 10 adult subjects possessing normal or near-normal vision.

Standard of visibility.	12-point.	Footcandles on Printed Matter.		
		10-point.	8-point.	6-point.
5 Footcandles on 12-point type.....	5	7	10	17
10 Footcandles on 12-point type.....	10	15	21	36
20 Footcandles on 12-point type.....	20	28	42	68
50 Footcandles on 12-point type.....	50	71	93	167

It will be noted that 6-point Bodoni type is of the same visibility as 12-point type when the intensity of illumination upon the smaller size is about three and a half times that upon the larger size. In general, this relationship between type-size and intensity of illumination is independent of the standard of

visibility. Furthermore, deficiencies in type-size, at least for the sizes between 6-point and 12-point, may be compensated by increases in the level of illumination which are practicable from the viewpoint of modern lighting.

Obviously, it is also possible to investigate the visibility of various kinds of printed matter when the latter is viewed by subjects possessing various degrees of subnormal vision. For example, the visibility of text matter used in sight-saving classes [3] and read by children with subnormal vision was compared to the visibility of the usual textbooks when read by children of normal visual ability. Certainly the former class needs even more visual assistance, relatively, than the latter; and the Visibility Meter technique provides a means for appraising these factors upon a reliable quantitative basis.

SUMMARY.

In the absence of an adequate scale for evaluating any contributions to visual efficiency and human welfare, this phase of the present investigation may be presented in general terms. Perhaps the importance of type face, as a variable in seeing, is summarized by the viewpoint that modern visual tasks are so severe and exacting that *any* contribution towards ease in seeing is definitely worthwhile. Upon this basis, it would seem that the present method of appraising the visibility of type faces might well be applied generally, and in particular, to the type faces used in school text-books. Where the type faces are unchangeable it is seen that illumination (footcandles) can be used to obtain the desired degree of visibility or ease of reading.

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4. "Visual Tasks in Sight-Saving Classes," M. Luckiesh and Frank K. Moss, *American Journal of Ophthalmology* 19, 1936, 992.
5. "Visibility: Its Measurement and Significance in Seeing," M. Luckiesh and Frank K. Moss, JOURNAL OF THE FRANKLIN INSTITUTE, **220**, 1935, 431.

DERIVATION OF COEFFICIENTS OF ORIFICES.

BY

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In the *Journal of the Society for the Promotion of Engineering Education*,[1] there appears a theoretical derivation of the coefficient of contraction by Professor Hooper. It is based upon the principle of the conservation of momentum and an assumption for the distribution of velocities of particles in contact with the wall in which the orifice is located.

The momentum imparted to the moving water is equal to the sum of the two unbalanced forces acting upon the water in the vessel, namely: Awh and $\int da \times$ reduction in pressure due to velocity over all parts of the infinitely large wall surface in which the orifice is assumed to be placed. Here A is the area of the hole, w is the weight of the water per unit volume and h is the height of water over the center of the orifice and da is a differential area of wall surface.

This principle expressed in an equation becomes

$$Awh + \int da \times \text{pressure reduction} = \frac{a_1 w v_1^2}{g}, \qquad (1)$$

where a_1 and v_1 are the area and velocity respectively at the vena contracta.

Assuming that the pressure reduction at a given point in the water in contact with the wall surface is equal to $wv^2/2g$ where v is the velocity at this point and assuming that the velocity at this point is given by the equation $v = Q \div$ area of a hemisphere through this point with center in the center of the plane of the orifice, then $v = Q/2\pi r^2 = a_1 v_1/2\pi r^2$ where r is the radius of this hemisphere and Q is the rate of discharge.

The term in (1) which represents the total force of pressure

[1] Vol. XVI, No. 7, March 1926.

reduction is

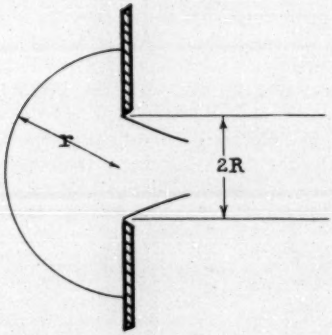
$$da \times \text{pressure reduction} = \int_R^\infty daw \frac{\left(\frac{a_1 v_1}{2\pi r^2}\right)^2}{2g}$$

$$= w \int_R^\infty 2\pi r dr \frac{\left(\frac{a_1 v_1}{2\pi r^2}\right)^2}{2g} = \frac{w(a_1 v_1)^2}{2\pi 2g} \int_R^\infty \frac{dr}{r^3}$$

$$= \frac{w(a_1 v_1)^2}{2g2\pi} \times \frac{1}{2} \times \frac{1}{R^2} = \frac{w a_1^2 v_1^2}{2g} \times \frac{1}{4} \times \frac{1}{A},$$

where R is the radius of the orifice.

FIG. 1.



Professor Hooper obtained for this $w(a_1 v_1)^2/2g \times 1/2 \times 1/A$, which is incorrect.

Assuming that $v_1^2/2g = h$ as did Professor Hooper and that $a_1/A = c$ the equation (1) becomes

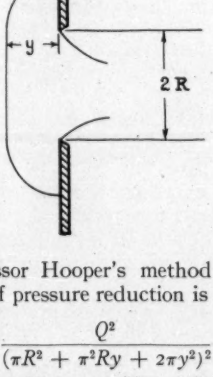
$$Awh + w\frac{v_1^2}{2g} \times \frac{a_1^2}{A} \times \frac{1}{4} = w2a_1 \frac{v_1^2}{2g}, \qquad (2)$$

$$wh\left(A + \frac{a_1^2}{4A}\right) = wh2a_1,$$

from which $1 - 2c + (c^2/4) = 0$ and $c = (2 - \sqrt{4 - 1})/1/2 = .536$ [2] instead of .59 as Professor Hooper computed.

This value appears to cast some doubt upon the validity of the assumption as to the distribution of velocity of the particles in contact with the wall. If the term in the above expression which represents the total force of pressure reduction on the wall surface were larger, then the coefficient would become larger and perhaps more nearly the expected value. Accordingly an investigation of the assumption was made that v at a point in contact with the wall $= Q \div$ the surface through this point which is everywhere the same distance from the nearest point (rather than the center) of the orifice. This surface resembles a bowl with a flat bottom.

FIG. 2.



Applying Professor Hooper's method to this case, the term for the force of pressure reduction is

$$w\int_0^\infty da\,\frac{v^2}{2g} = \frac{w}{2g}\int_0^\infty \frac{Q^2}{(\pi R^2 + \pi^2 Ry + 2\pi y^2)^2} \times dy(R + y)2\pi$$

$$= \frac{wQ^2 2\pi}{\pi^2 2g} \times \frac{1}{4}\int_0^\infty \frac{(R + y)dy}{\left(\frac{R^2}{2} + \frac{\pi R}{2}y + y^2\right)^2}, \quad (3)$$

[2] Since we originally made this calculation we found the same result arrived at by a slightly different method on page 167 of "Aufgaben aus der Technischen Mechaniks," 1921, III Band, by F. Wittenbauer.

where y is the distance from the surface to the nearest point in the plane of the orifice.

The integral becomes by the conventional method

$$\frac{\left(\frac{\pi R}{2}\right)^2 - 2R^2 + \left(2R - \frac{\pi R}{2}\right)\left(2y + \frac{\pi R}{2}\right)}{2\left(2R^2 - \left(\frac{\pi R}{2}\right)^2\right)\left(y^2 + \frac{\pi R}{2}y + \frac{R^2}{2}\right)} + \frac{2R - \frac{\pi R}{2}(4-3)}{2R^2 - \left(\frac{\pi R}{2}\right)^2} \times \frac{1}{\sqrt{\left(\frac{\pi R}{2}\right)^2 - 2R^2}} \log_e \frac{2y + \frac{\pi R}{2} - \sqrt{\left(\frac{\pi R}{2}\right)^2 - 2R^2}}{2y + \frac{\pi R}{2} + \sqrt{\left(\frac{\pi R}{2}\right)^2 - 2R^2}},$$

which on substituting limits becomes $1.1897/R^2$. Therefore (3) becomes

$$\frac{2Q^2w}{4\pi 2g} \times \frac{1.1897}{R^2} = \frac{Q^2w}{2gA} \times .5948.$$

The value of this integral is not appreciably reduced when the pressure reduction over all the area beyond a distance of say $4R$ from the center of the orifice is omitted. This accords with experiments which show that conditions of surface this distant from orifice do not affect coefficient.

Now following the method of Professor Hooper and making assumptions similar to his, the equation becomes

$$Awh + w\frac{a_1^2v_1^2}{A2g} \times .5948 = 2wa_1\frac{v_1^2}{2g} \qquad (4)$$

or

$$1 - 2c + .5948c^2 = 0,$$

from which

$$c = \frac{2 - \sqrt{4 - 2.379}}{2 \times .5948} = .611.$$

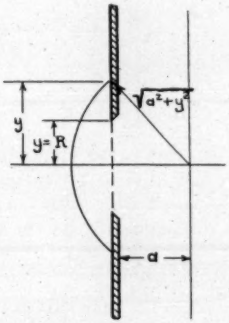
This value of c is more nearly in accord with the results of experiments. Bazin found values of the coefficient of

discharge for orifices ranging between .597 to .627. These are reported in "Experiments upon the Contraction of the Liquid Vein" translated by Trautwine.

Similar results were obtained by assuming that the surface is a portion of a sphere whose center is some fixed distance in front of the center of the plane of the orifice. In this way the velocity of the particles in contact with the wall at a point y distant from the center of the orifice is given by the following expression:

$$v = \frac{Q}{2\pi(a^2 + y^2 - a(a^2 + y^2)^{1/2})}. \qquad (5)$$

FIG. 3.



Then pressure reduction equals

$$w\int_R^\infty da\,\frac{v^2}{2g} = \frac{w}{2g}\int_R^\infty \left[\frac{Q}{2\pi(a^2 + y^2 - a(a^2 + y^2)^{1/2})}\right]^2 2\pi y dy$$

$$= \frac{2\pi w}{2g}\left(\frac{Q}{2\pi}\right)^2 \int_R^\infty \left[\frac{1}{a^2 + y^2 - a(a^2 + y^2)^{1/2}}\right]^2 y dy.$$

Integrating by substitution. Let

$$a^2 + y^2 = x^2.$$

Then

$$2ydy = 2xdx,$$

$$dy = \frac{x}{y}dx.$$

And when

$$y = R, \qquad x = \sqrt{R^2 + a^2}.$$

Substituting these values

$$\frac{2\pi w}{2g}\left(\frac{Q}{2\pi}\right)^2 \int_{\sqrt{R^2+a^2}}^{\infty} \left(\frac{1}{x^2 - ax}\right)^2 y \frac{x}{y} dx = \int_{\sqrt{R^2+a^2}}^{\infty} \left[\frac{1}{x(x-a)}\right]^2 x dx$$

$$= \int_{\sqrt{R^2+a^2}}^{\infty} \frac{x dx}{x^2(x-a)^2} = \int_{\sqrt{R^2+a^2}}^{\infty} \frac{dx}{x(x-a)^2}.$$

Further integration, using the method of partial fractions, gives the following result:

$$\text{Pressure reduction} = \frac{2\pi w}{2g}\left(\frac{Q}{2\pi}\right)^2 \left[\frac{1}{a} \times \frac{1}{\sqrt{R^2 + a^2} - a} - \frac{1}{a^2} \log_e \frac{\sqrt{R^2 + a^2}}{\sqrt{R^2 + a^2} - a}\right]. \quad (6)$$

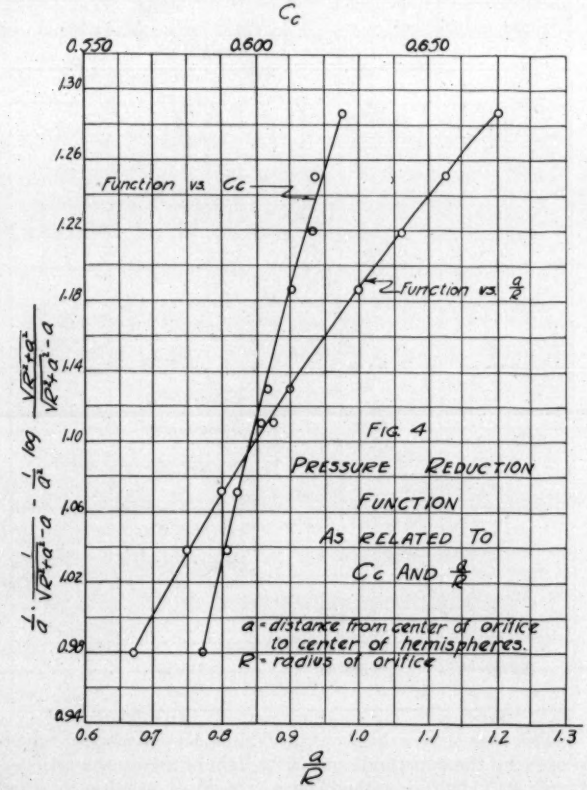
In order to obtain the same value for the coefficient as that obtained above, i.e. $c = .611$, the portion of the above term in the brackets should equal $1.1897/R^2$. Selecting various values of a and substituting in the expression until the desired answer was obtained, it was found that the coefficients are the same when $a = 1.014R$, that is, when the center of the sphere is approximately one radius in front of the center of the orifice.

Continuing this method using various values of a/R in computing the coefficients the following table was obtained:

$\frac{a}{R}$	$\frac{1}{a}\frac{1}{\sqrt{R^2 + a^2} - a} - \frac{1}{a^2}\log_e \frac{\sqrt{R^2 + a^2}}{\sqrt{R^2 + a^2} - a}$	C_c
0.600	$0.93921/R^2$	0.578
0.667	0.9800	0.584
0.750	1.0380	0.591
0.800	1.0708	0.594
0.875	1.1154	0.601
0.900	1.1298	0.603
1.000	1.1864	0.610
1.0625	1.2190	0.616
1.125	1.2507	0.617
1.200	1.2685	0.625

From this table curves were constructed showing the relationship between the expression

$$\frac{1}{a} \times \frac{1}{\sqrt{R^2 + a^2} - a} - \frac{1}{a} \log_e \frac{\sqrt{R^2 + a^2}}{\sqrt{R^2 + a^2} - a}, \frac{a}{R} \text{ and } C_c \text{ (Fig. 4).}$$



With this data another curve was constructed showing the influence of the assumed position of the center of the spheres upon the resulting computed coefficient of contraction (Fig. 5).

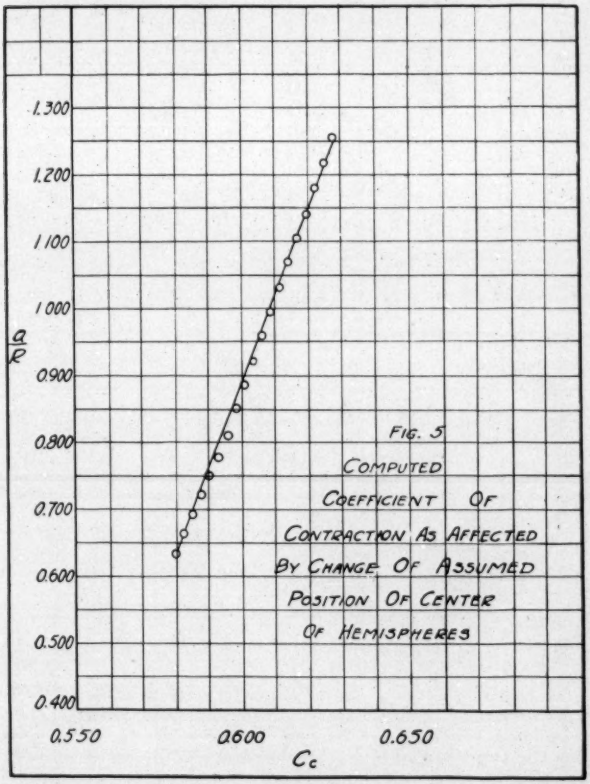


FIG. 5
COMPUTED COEFFICIENT OF CONTRACTION AS AFFECTED BY CHANGE OF ASSUMED POSITION OF CENTER OF HEMISPHERES

The case of two dimensional flow is also of interest when studied by these methods and in the light of these assumptions. Lamb in "Hydrodynamics" has arrived at a value for this

coefficient with a perfect fluid of .611 for this case. Using a surface whose cross-section is shown in Fig. 2, the total force of pressure reduction is

$$w\int_0^\infty da\frac{v^2}{2g} = \frac{Q^2}{2g}w\int_0^\infty \frac{2Ldy}{(2R+\pi y)^2L^2},$$

where L is the length of the orifice and R is half the depth of the orifice and y is the distance between the surface and the nearest point in the plane of the orifice. (See Fig. 2.)

This integrates readily into

$$w\frac{Q^2}{2g}\times\frac{2}{L}\times\frac{1}{\pi}\left[\left(\frac{1}{2R+\pi y}\right)\right]_0^\infty = w\frac{Q^2}{2g}\times\frac{2}{L}\times\frac{1}{\pi}\times\frac{1}{2R}$$

or $wa_1^2v_1^2/2g \times 2/\pi \times 1/A$, where as before v_1 and a_1 refer to the vena contracta and A is the area of the hole.

The equation for the coefficient is

$$Awh + \frac{wa_1^2}{A}\times\frac{v_1^2}{2g}\times\frac{2}{\pi} = \frac{2a_1v_1^2w}{2g}.$$

Assuming $h = v_1^2/2g$ (i.e. $C_v = 1$) and that $a_1/A = c$ and dividing by A we get $1 + c^2(2/\pi) - 2c = 0$, from which

$$c = \frac{2-\sqrt{4-8/\pi}}{4/\pi} = \frac{.7943}{1.273} = .624.$$

Precisely the same value for the pressure reduction term and consequently for the value of C_c is obtained using cylindrical surfaces with the center of the cylinders one radius distant from the plane of the orifice.

Bazin in the book referred to above gives as the mean of his experiments upon this type of orifice .6266.

The theory of Professor Hooper would indicate a very interesting connection between the coefficients of velocity and of discharge. (In the previous analyses the coefficient of velocity has been assumed to be unity.) The larger the coefficient of velocity is assumed to be, the larger is the computed coefficient of contraction and the smaller the resulting coefficient of discharge. This is true for the assumption of radial flow made by Professor Hooper as well as for the other assumptions made above.

Thus for the second case considered above $v_1^2/2g = C_v^2 h$ where C_v = Coefficient of velocity. So the equation (4) becomes

$$Aw\frac{v_1^2}{2g} \times \frac{1}{C_v^2} + w\frac{a_1^2}{A} \times \frac{v_1^2}{2g} \times .5948 = 2wa_1 \times \frac{v_1^2}{2g},$$

and this becomes $1/C_v^2 + .5948C_c^2 - 2C_c = 0$, where C_c = Coefficient of Contraction. So

$$C_c = \frac{2 - \sqrt{4 - \frac{2.379}{C_v^2}}}{1.1897}.$$

Hence when $C_v = 1.00$, $C_c = .611$ and $C_q = .611$; when $C_v = .99$, $C_c = .627$ and $C_q = .621$; when $C_v = .98$, $C_c = .643$ and $C_q = .630$, where C_q = Coefficient of Discharge.

Applying this method to the case of a tube with sharp edges in the plane of the wall with a coefficient of contraction for the tube assumed to be unity the above equation becomes $1/C_v^2 + .5948C_c^2 - 2C_c = 0$, whence $C_v = .844$.

However, if allowance be made for loss in momentum due to pipe friction of $wA \times fl/d \times v^2/2g$ when $f = .025$ and $l = 3d$ then this expression becomes $Aw \times .075(v^2/2g)$. And the above equation becomes $1/C_v^2 + .5948C_c^2 - 2.075C_c = 0$. So $C_v = .822$.

Weisbach gives a value for tubes of .810 to .840 with a mean of about .815.

A study of these two examples indicates that the allowance for pressure reduction which this particular assumption makes may be slightly too large and that the value Professor Hooper arrived at however incorrectly in his original article may be more nearly in accord with the facts.

This derived inverse relationship between C_v and C_q helps to explain the observed paradox that, within certain limits, the greater the viscosity of the fluid (or the less the fluidity or the less the Reynold's number) the greater the rate of flow and consequent coefficient of discharge. An increase in the viscosity would naturally decrease the velocity at a given head and this would mean a decrease in the value of C_v which, in accordance with the relationship stated above would

so increase the area of the vena contracta and of C_c as to result in an increase of flow and of C_q.

It must be admitted that there is very little justification for using the assumptions of velocity distribution here chosen except that they yield reasonable values of C_c. It appears very unlikely that the velocities would everywhere be of the same magnitude in a particular surface and normal to this surface at the same time so that $Q = da \times v$ for this surface, where A is the surface area and v is the normal velocity—a constant for the entire surface. Bazin's investigations indicate that there is no such surface. Yet it might happen that v as so computed would be the actual velocity at the point of contact with the wall as has been assumed. The normal surface to the stream lines is very likely more elliptical in shape than has been assumed and the velocity in the normal surface may not be constant. This leads to the opinion that a rigorous derivation of the coefficient must be based upon the methods of Hydrodynamics, such as are used by Lamb quoted above. But until that derivation is available, such studies as this one may be useful in elucidating certain of the baffling experimental results.

SUMMARY.

1. A mistake in the original derivation of coefficient of contraction by the method of Professor Hooper has been pointed out.

2. The method has been reapplied to the circular orifice using a slightly different assumption of velocity distribution based upon a compound surface and the method has been extended to the rectangular orifice. Results have been obtained which are fairly close to experimental values, assuming velocity coefficients unity.

3. The method has also been applied to spherical surfaces whose centers are not in the plane of the orifice. Results in agreement with those of the previous analysis have been obtained when the center of the sphere or of the cylinder was assumed to be about one radius distant from the plane of the orifice. A general relation between this distance and the resulting computed coefficient of contraction has been derived for the circular orifice.

4. A further study has been made of the influence of the coefficient of velocity upon the coefficients of contraction and discharge and the coefficient of discharge of the tube has been derived which appears only slightly larger than the more plausible experimental values.

5. Inconsistencies in certain of the assumptions of this method have been admitted and the opinion expressed that a rigorous derivation of the coefficient of contraction must be based upon the classical methods of hydrodynamics.

6. The derived relations between the coefficients help to explain the well-known paradox of the inverse relation between fluidity and rate of flow which apparently has not yet been studied by the more elegant mathematical methods.

CLOCKS SHOWING MEAN AND SIDEREAL TIME SIMULTANEOUSLY.

BY

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Astronomers have always commanded the best and most willing services of the clockmaker, who holds them in reverence as if they were the authors of time itself. He reaches the summit of his ambition when he supplies a sidereal clock for the observatory, but he is a little lacking in imagination and has failed to offer the astronomer what he really wants in the way of a sidereal dial as a trusty companion in the dome. It has always been assumed that such a clock must be provided with a sidereal pendulum, and that an appropriate price for it would be little less than for the clock in the basement used for time determination.

An obvious alternative in an observatory is a circuit of electrical impulse dials, driven from a master clock,—an electrical time transmitter in its simplest form, with a pendulum beating sidereal seconds. The economy and convenience of such an installation has been overlooked, particularly in those observatories that happen to be equipped with the Shortt free pendulum, and hence already have their sidereal master clocks in the form of transmitting slaves. It is apt to be forgotten that it involves no risk of interference with the fundamental free pendulum and that, whatever its rate may be, a correction of $\pm$ 1 second can be readily effected on the slave. However, it has not been thought worth while to run a purely sidereal electrical time circuit through an observatory, and so far as this country is concerned, it is probably too late, as there is something better to offer.

On the other hand, Paris Observatory installed a sidereal time service last year. Their clocks, however, do not give sidereal time alone, but are provided with two dials, showing sidereal and mean time; this undoubtedly makes the installa-

tion worth while. The dials are coupled with wheelwork that expresses very nearly the correct ratio of mean to sidereal time. The precise expression of this ratio by gear trains is an interesting problem, and the Paris enterprise suggested an investigation of the many ingenious attempts to realize it.

Since one mean solar day = $24^h\ 03^m\ 56^s.555\ 36$ in sidereal time, the ratio of sidereal to mean time is 1.002 737 909 3. A more accurate value of this ratio is given below.

The history of the mathematical methods of finding rational approximations to unwieldy decimals is interesting, but need not be discussed here. Suffice it to say that the above ratio must be expressed by a fraction; for our purposes the numerator and denominator of this fraction must both be factorizable into factors not exceeding a few hundreds, as the number of teeth on any wheel cannot reasonably exceed this. Moreover the number of factors (or suitable combinations of them) in the numerator and denominator must be the same, as wheels must work in pairs.

No clockmaker attempted a clock with such a gear train until the nineteenth century. Daniel Quare, who died in 1724, made a combined mean and sidereal clock, now in the President's house, Royal Naval College, Greenwich, with two separate and independent movements. Breguet (1727–1823) did the same in several of his watches. George Margetts, who became a liveryman of the Clockmakers' Company in 1799, made a watch—now in the Company's collection at the Guildhall—that had three independent dials for hours, minutes and seconds, each having a smaller dial mounted concentrically with the larger. These inner dials were gradually revolved backwards by gearing, so that the same three hands indicated simultaneously mean time on the outer dials and sidereal time on the inner dials. Margetts was the pioneer, since he was the first to show mean and sidereal time with a single movement. His train includes a wheel with 487 teeth so fine that they are invisible to the naked eye. The ratio is $\frac{1465}{1461} = \frac{5 \times 293}{3 \times 487} = 1.002\ 737\ 85$ (which is correct to the sixth decimal), but the cutting of a wheel with 293 teeth was ingeniously avoided by gearing to give a relative motion

of $\frac{4}{1461}$ i.e., 0.002 737 85. The sidereal component would lose at the rate of $1^s.8$ a year.

In the South Kensington Museum there is a clock designed by Joseph Vines a hundred years ago (1836), with two dials coupled by the ratio $\frac{43 \times 247}{32 \times 331}$. This is 1.002 737 915 4, which is correct to the seventh decimal. It will take 5.2 years for the sidereal dial to be in error relatively to the solar dial by one second.

In the *Monthly Notices* of 1849 Dec. 14 and 1850 May 10, Sir George Airy contributed three sets of possible trains as a communication from Dr. Henderson. The first of these is Vines' train as above, and the third should be mentioned as one of outstanding merit. It is $\frac{50 \times 182 \times 196}{30 \times 211 \times 281}$, a ratio of 1.002 737 908 5. This is very close, being correct to the ninth decimal, but is rather cumbersome. Vines' train as above appears again in the excellent paper of Monsieur Ernest Esclangon in *L'Astronomie*, 1935, p. 215, but he discarded it in favor of $\frac{119 \times 317}{114 \times 330}$ when installing the set of double dial clocks in the Paris Observatory. The product is 1.002 737 905 4, which is correct to the eighth decimal. This train originated with Ungerer, who made a clock for the Strasbourg Observatory in which it is used.

At this stage of the investigation I was fortunate in interesting Dr. L. J. Comrie who, as a result of "a pleasant week-end's arithmetical recreation," sums up the whole matter and contributes a solution that we may accept as final. He points out that the ratio of sidereal to mean time must be derived from Newcomb's right ascension of the mean sun, namely $18^h\ 38^m\ 45^s.836 \times 8640184^s.542T + 0^s.0929T^2$ where T is measured in Julian centuries of 36525 days from 1900 January 0.0 G.M.T. Hence the ratio *now being used in the ephemerides* is

$$1 + \frac{8640184.542 + 0.1858T}{8640000 \times 365.25}$$
$$= 1.002\ 737\ 909\ 265 + 0.000\ 000\ 000\ 059T.$$

As the result of a systematic examination of possible fractions Dr. Comrie found $\frac{821115}{818873} = \frac{3 \times 3 \times 5 \times 71 \times 257}{11 \times 17 \times 29 \times 151}$ = 1.002 737 909 297, which is the value of the ratio required in 1955. This can be expressed in wheelwork as $\frac{45 \times 71 \times 257}{29 \times 151 \times 187}$. No clock started in this century would attain a relative error of $0^s.001$ by the end of the century; the error would amount to 1^s in about 100,000 years.

The various schemes may be compared.

	Max. no. of Teeth.	Ratio Achieved.	Years to Get 1^s Out.
With two pairs of gears.			
Margetts, 1800	487	1.002 737 85	0.5
Vines, 1836	331	1.002 737 915 4	5.2
Ungerer—installed at Paris in 1935	330	1.002 737 905 4	8.2
With three pairs of gears.			
Henderson 1850	281	1.002 737 908 5	42
Comrie, 1936	257	1.002 737 909 297	100,000

So far as is known, Paris is the first observatory to be equipped with a combined mean solar and sidereal time service. Doubtless it will be found a great convenience, but it suffers from a shortcoming common to every mean solar and sidereal clock yet made. The combined clock has invariably derived its time from a pendulum driven by an escapement, in steps dependent on the period of a balance wheel or a pendulum; hence it is necessary to decide whether to rate it for mean solar time and gear it up to sidereal time, or vice-versa. Whichever is chosen, the progression of the wheelwork, and therefore the hands of *both* dials, will advance in seconds of the same length. If it is dead-beat on the divisions of the mean time dial, the pointer will creep forward progressively on the sidereal dial, gaining a second in about 6 minutes; conversely, if the clock is rated to be dead-beat on the sidereal dial, it will creep backwards on the mean dial. Thus a dead-beat reading on both dials is never attained.

By means of a simple device, however, the problem of

giving dead-beat seconds hands on both dials has been solved. The solution may be demonstrated by three clocks, each with its pair of dials, representing an upward effort to achieve an accurate ratio. The first is $\frac{366}{365}$, which may be realized by the simple train $\frac{30 \times 61}{25 \times 73}$. It was adopted by Stromgren and Olsen in 1915 in their navigators' watch. Its error of $57^s.3$ a year can be neatly corrected by a differential gear, the normally fixed member of which is moved backwards in weekly steps, so that the error can be almost wiped out by this means. The second is $\frac{43 \times 247}{32 \times 331}$. This is the same as in Vines' clock of 100 years ago; the sidereal seconds hand gains one second in a little over five years. The third is Dr. Comrie's train, which is altogether free from sensible error. The great feature of these models is the jump seconds on both dials, true to both mean solar and sidereal. This dead-beat action is produced by a one-leaf pinion picking up the teeth of a 60-toothed escape wheel.

It will be observed that in quoting the numberings of the trains selected, mean solar time is taken as the basis and geared upwards to sidereal time, whereas the Paris clocks gear sidereal down to mean time. The question naturally arises,—why has this been done? The answer is that these are synchronous motor clocks, driven by the alternating current that is supplied to the nation through the grid system. Since the *average* frequency of 50 cycles a second is rigidly maintained, there is no cumulative error in the time-keeping of a synchronous motor clock, although there may be fluctuations (not exceeding 10^s in recent years, and rarely more than 5^s) about the true time.

The accuracy of the timing of the grid is ample for the main driving of equatorials; a subsidiary control to take care of refraction, periodic errors and fluctuations in the alternating current frequency is, of course, necessary in refined work such as photography. The automatic time control of the speed of our turbo-alternators is an ambition that has already been realized in individual stations. The conditions laid down by

the Central Electricity Board for the technical management of the grid are such that the disturbances inevitably caused by load sharing will be progressively diminished. Astronomers can help the campaign to improve the timing of the grid by making their requirements known.

In the meantime either end of the wheel train of these clocks can be synchronized from the slave clock of a free pendulum by half-minute impulses. Any one of these synchronized double dial clocks can operate contacts at either end to transmit sidereal or mean time seconds, or both, to operate circuits of electrical impulse dials with unimpeachable accuracy. For those who fear breakdowns, in spite of the steady progress of our generating stations towards the high standard of continuity of service that they have set themselves, a simple little instrument is available to take up the duty automatically if the alternating current is cut off.

It should be remarked that the ratio we have been dealing with is that between mean solar time and mean sidereal time. To get apparent sidereal time, the nutation in right ascension, which may amount to $\pm$ 1^s.2, must be added to mean sidereal time. Hence for use in dials in the dome, etc., the extreme accuracy of Comrie's train would rarely be needed. Since, however, a sidereal free pendulum in a modern time-determining observatory refuses to alter its rate in conformity with the wobble of the earth's axis, ignores nutation and keeps mean sidereal time, his train could be used to produce a mean solar time system for the transmission of time signals. But this would imply a sidereal of zero rate, or a duplicate sidereal frequently corrected. If it were possible, then the continual comparison of the standard mean and sidereal clocks would be eliminated.

Synchronous motor clocks are destined to prove extraordinarily useful for purposes that were not visualized at the time of their introduction in the United States in 1919, although forty years ago the author forecast that they would be the electric clocks of the future. This combination of mean time and sidereal time clocks is just another instance of the utility of the synchronous motor method.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

IMPROVED ASTROGRAPHIC CAMERA.

About two years ago a 9-inch astrographic camera lens was designed by I. C. Gardner, chief of the optical instruments section, and last year this lens was constructed in the Bureau's optical shop from glass produced by the Bureau's glass plant. The lens, which is of the telephoto type, consists of 4 components grouped into two well separated doublets, and was specially constructed for eclipse work. It was corrected for a field 20 inches square, corresponding approximately to $4\frac{1}{2}$ degrees.

A camera and mount for this lens was constructed of aluminum. In designing the mount the purpose was to make the complete equipment as light as possible for ease of transportation and to make the camera self-contained so that the focusing could be done in the laboratory before the equipment was packed for shipment. The plate holder was driven by clockwork so as to follow the sun's image, the camera remaining stationary.

The National Geographic Society and the Bureau cooperated in sending Doctor and Mrs. Gardner with this apparatus to Ak Bulak, in western Siberia, where photographs were made during the total eclipse of June 19, 1936. Six satisfactory color films and two black and white negatives of the corona were made. On account of the excellent definition over the entire field, the outer corona can be traced to the extreme edges of the plates. The structure of the inner corona, particularly those lines indicating the presence of magnetic fields, is also faithfully recorded.

SELECTION OF COLORS FOR SIGNAL LIGHTS.

At the request and with the financial support of the Bureau of Aeronautics, Navy Department, an investigation

*Communicated by the Director.

was undertaken by H. J. McNicholas at the Bureau to determine the best color limits for signal lights constituting a six-color system. The choice of suitable colors for any signal system is determined primarily by the number of colors required and the service conditions. In the present application the lights must be readily identified over a distance of approximately 1,500 feet, under weather conditions varying from a clear atmosphere to light haze. The signals are seen and identified as point sources of low intensity, and the colors are limited to those obtainable by combinations of an incandescent lamp and colored-glass cover globes.

Under these service conditions the problem is reduced to a choice between two six-color systems. One system consists of red, orange-yellow, white, green, blue and purple. The other system consists of red, orange, yellow, white, green, and blue.

The best ranges of each color were determined and comparison made between the two systems. The work was done on an outdoor test range by groups of normal observers, under test conditions closely simulating those required in service. Various test colors were exhibited at different signal intensities in random order, and observers were asked to assign each color to one of the 6 permitted color classifications. In this way approximately 58,000 single observations were recorded in the selection of the colors and their tolerance limits.

As described in the December number of the *Journal of Research* (RP956), it was found that the orange and yellow were the least distinctive as signal colors when both are used with red and white. Permissible tolerances were also found to be too restricted for easy reproduction of the colored glassware. Furthermore, these orange and yellow colors are not stable with varying distance and appear shifted toward the red as the distance is decreased (higher signal intensity).

Considerable difficulty was experienced in the discrimination between green and blue and it was found that a highly-saturated "sextant" green was required to gain the maximum distinctiveness from a saturated blue. At long distances (low signal intensities) a definite tendency to confuse the green and blue is unavoidable.

Purple, in general, is not a good long-distance signal color because of the low transmission of light by all purple-glass cover globes and the well-known dichromatic nature of this signal when seen as a very small source. This color proved to be very distinctive, however, when the signal intensity was made comparable with that of the other colors. This required a lamp intensity at least 21 times that required for white or yellow signals.

On the whole, the tests favor the selection of red, orange-yellow, white, green, blue, and purple as the best six-color signal system for the required service conditions.

ABSOLUTE DETERMINATION OF GRAVITY.

The absolute determination of gravity at Washington, which has been carried on by Paul R. Heyl and G. S. Cook for the past six years, has been completed and the results will be published in the December *Journal of Research* (RP946). This is the first absolute precision determination that has been made anywhere in the world since that at Potsdam, Germany, published in 1906. Attention may be directed to a number of points of special interest in the present determination.

The work was done with three pendulums of fused silica, to eliminate temperature corrections as nearly as possible. In addition, the standard scale used to measure the lengths of the pendulums was also of fused silica.

Especial attention was given to the flexure correction, which arises from the fact that a pendulum bends slightly as it swings. While this effect can be demonstrated to be present to a considerable extent in either the down or up position of a swinging pendulum, it was found experimentally to be partly eliminated in the reversal of the pendulum. (*B. S. J. Research*, **8**, 657 (1932); RP444.)

The factor causing the greatest variation in the results was found to be the knife edge. Both the material of the knife edge and the sharpness of its edge were found to be of importance. The material of the supporting plane, on the other hand, was of secondary importance.

The result obtained for the value of gravity at this station is 980.08 cm./sec.^{2}. This value is less than that given by

direct comparison with the station at Potsdam, Germany, by 2 parts in 100,000. A discussion of the probable cause of this difference is given.

PROPERTIES AND INDUSTRIAL USES OF SILVER.

Silver is one of the few metals, the history of which can be traced back to the earliest days of antiquity. Its position in the field of industrially-useful metals has recently become of increasing importance. This renewed interest in silver as an engineering material is a natural consequence of its rather remarkable physical properties. In several important respects silver stands at the head of the list of metals.

For many years silver has been a convenient material for physicists to use in their observations of the workings of physical laws, and much information has been accumulated in this way. The increasing interest in silver has created a demand for information on its physical properties, but, because these data were widely scattered in the technical literature, they were not readily available. Recently, through a coöperative arrangement with a group of eight of the leading silver producing companies of the United States, the Bureau was enabled to make a survey of the technical information on silver and assemble it into a conveniently usable form. Much additional information, hitherto unpublished, was obtained by visits to, or correspondence with, those interested in the use of silver.

The assembled information is being published as Circular C412, "Silver: Its Properties and Industrial Uses." It is arranged in three parts. The first part deals with the physical, chemical, and technological properties of the pure metal. The second part presents the available data on a number of the commercially important alloys of silver with base metals. In the third part are discussed industrial uses of silver, in three groups: electrical, chemical, and bactericidal. A comprehensive bibliography citing the original sources of information is appended to each section of the Circular. Copies of this publication are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents each.

OXIDE FILMS AS A PROTECTION AGAINST WEAR.

The effect of oxygen-free atmospheres (nitrogen and hydrogen) upon the wear of a hypoeutectoid, a eutectoid, and a hypereutectoid carbon steel has been studied by S. J. Rosenberg of the Bureau's metallurgical division. It was found that when these steels were hardened and subsequently tempered at low temperatures, the rates of wear were comparatively low; the wearing surfaces were smooth and were covered by a thin oxide film, and the abraded particles consisted of Fe_2O_3 and Fe_3O_4. When these steels were tempered above certain temperatures, the rates of wear were extremely high; the worn surfaces were very rough and bright and the abraded particles were metallic iron. When tested in air all steels were covered with an oxide film and the rates of wear were low.

BOILING POINTS OF ORDINARY AND HEAVY WATER.

The differences between the boiling points of dilute aqueous solutions of heavy water and the boiling point of ordinary water were measured by Edgar R. Smith and Mieczyslaw Wojciechowski in the range from 0.3 to 7 per cent. of heavy water (deuterium oxide). The boiling points were found to increase linearly with increase in D_2O, according to the equation mole $\%$ $D_2O = 70.9(\Delta T)$, where ΔT is the boiling point in ° C. minus 100. The measurements, made with ebulliometers of the type devised by W. Swietoslawski, were found to offer a rapid method for the analysis of solutions of heavy water.

The differences between the boiling points and condensation temperatures of the same solutions were measured in a differential ebulliometer which gave a fractionation equivalent to about one theoretical plate. The small separation between the vapor and liquid lines on the boiling point-composition diagram shows that the separation of heavy water by fractional distillation would require columns of extreme efficiency. For a more complete account of this work, RP947 in the December number of the *Journal of Research* should be consulted.

PHYSICAL PROPERTIES AND CHEMICAL CONSTITUTION OF LUBRICATING OIL FRACTIONS.

A considerable divergence of opinion exists concerning the chemical constitution of the higher boiling fractions of petroleum. An investigation of this question by Beveridge J. Mair and Charles B. Willingham at the Bureau in cooperation with the American Petroleum Institute, is described in the *Journal of Research* for December (RP954). In this work the properties of extensively distilled and extracted fractions of lubricating oil have been correlated and compared with the properties of synthetic hydrocarbons of high molecular weight. The results show that the least soluble portion of the oil (the material corresponding to the most highly refined product obtained by any good solvent extraction process) consists substantially of naphthenes (cycloparaffins) containing from one to about three rings to the molecule, together with the necessary alkyl radicals. The somewhat more soluble portion consists of naphthenes with more rings, together with some unsaturated hydrocarbons and possibly some aromatic hydrocarbons. There is no evidence whatever for the presence of iso or branched-chain paraffins.

Because of the similar solubility relations, it is possible that in the extraction processes as used at the present time one-ring aromatic hydrocarbons are being discarded to waste along with the undesirable naphthenes containing about six rings to the molecule. This is a point well worth investigating since these one-ring aromatic hydrocarbons may be of a valuable constituent for good lubricating oil.

PHYSICAL PROPERTIES OF ISOPRENE.

The relation between isoprene and rubber is being studied by Norman Bekkedahl, Lawrence A. Wood, and Mieczyslaw Wojciechowski at the Bureau. It has long been known that natural rubber when heated to an elevated temperature yields isoprene, and conversely that isoprene under other conditions polymerizes to form a synthetic rubber. A clear understanding of this apparently reversible reaction can best be gained from a consideration of the free energies and other thermodynamic properties of the rubber and the isoprene.

Thermodynamic measurements on rubber were reported in *J. Research N. B. S.* **15**, 503 (1935) (RP844), and similar measurements on isoprene are now in progress.

This work requires that isoprene be prepared in a state of high purity. Inasmuch as there is considerable variation among the values of the physical properties of isoprene as reported by different observers, it has seemed worth while to make careful determinations of these values on freshly purified samples. The results of this work are reported in RP951 in the *Journal of Research* for December, and may be summarized as follows: Normal boiling point, 34.076 ± 0.003° C.; change of boiling point with change of pressure, 0.0383 ± 0.0001° C./mm. Hg; freezing point, − 146.8 ± 0.2° C.; density at 20° C., 0.6805 ± 0.0001 g./ml.; refractive index at 20° C., 1.42160 ± 0.00005. The volume coefficient of expansion was measured from the freezing point to the normal boiling point, with results expressed by the following equations:

$$V = V_0(1 + 1.393 \times 10^{-3}t + 2.79 \times 10^{-6}t^2 + 4.31 \times 10^{-9}t^3 - 5.60 \times 10^{-12}t^4),$$

$$\rho = 0.7002 - 0.9754 \times 10^{-3}t - 0.592 \times 10^{-6}t^2 + 0.525 \times 10^{-9}t^3 + 9.66 \times 10^{-12}t^4,$$

in which V and ρ are the volume and density, respectively, at the temperature t, and V_0 is the volume at 0° C. From the Clausius-Clapeyron equation the latent heat of vaporization at the normal boiling point was calculated to be 25.8 ±0.3 kj/mole (6.17 ± 0.07 kcal/mole). The refractive index at any temperature t from about 0° C. to the boiling point may be calculated from the equation $n_D = 1.43472 - 0.0656 \times 10^{-3}t$. The isoprene was found on standing to undergo a transformation, presumably oxidation and polymerization, as was indicated by an increased difference between boiling and condensation temperatures and also by changes in boiling point, density, and refractive index.

It is anticipated that this work on isoprene may be of interest in fields other than that of rubber, since there is evidence that isoprene is an intermediate product in the formation of terpenes in nature, and also that it may play an important role in the formation of plant cells.

STABILITY OF MOTION PICTURE FILMS.

Motion picture film of the safety type shows great promise as material on which to preserve records of permanent value, according to tests made by John R. Hill and C. G. Weber of the Bureau's paper section, and reported in the *Journal of Research* for December (RP950). This type of film, which has a base of cellulose acetate, is designed for use where the highly combustible film of the ordinary theatre type, the base of which is cellulose nitrate, presents too great a hazard from fire and explosion. In addition to its safety features, it appears to have the additional advantage of being much more lasting. Both types of film were studied by determining the effects of various accelerated aging treatments on samples of new film. Samples of old nitrate film were tested also to ascertain their condition after natural aging.

The most satisfactory accelerated aging treatment was found to be that employed in determining the relative stability of record papers. This treatment consists in heating the film in a dry oven, at 100° C. The physical and chemical properties of the films were determined before and after oven-aging tests of various durations, and changes in the properties noted. High retention of folding endurance and viscosity and small increase in acidity are considered indicative of stability. The acetate film was found to be excellent in these respects. Large losses in folding endurance and viscosity, and large increases in free acid in the material characterized the changes in nitrate film under the heat test. Its poor stability was further indicated by rapid decrease in resistance to a stability test used to determine the condition of smokeless powder.

The cellulose acetate film withstood oven-aging for 120 days without serious chemical or physical deterioration, while the nitrate film became useless after 10 days under the same conditions. The acetate appears to have lasting qualities comparable to those of permanent record papers of high quality, and the optimum atmospheric conditions for the preservation of paper records are likewise suitable for this film. Nitrate film is perishable and its deterioration is greatly accelerated under warm, moist conditions. The preservation of valuable nitrate film is a complicated problem

involving both elaborate fire protective measures and air conditioning.

EFFECT OF FIBER COMPONENTS ON STABILITY OF BOOK PAPERS.

Through many experiments, the Bureau has shown that relatively permanent book papers can be made from a number of the papermaking fibers in common use today.

The suitability of book papers for temporary use is evident, but their life expectancy is not so apparent. As to the longevity required, book papers range from papers for permanent records to those for current use only. The initial cellulosic purity of the papers, as well as conditions of use and storage, influences their resistance to reactions that induce deterioration. In the Bureau's paper section, Merle B. Shaw and Martin J. O'Leary are studying the relation of papermaking materials and processes to the stability of book papers. The study includes the effects of the components of fibers commonly used in fine printing papers, of filling and sizing materials, and of mineral coating materials. Unsized experimental papers have been made from a number of commercial book-paper fibers—wood pulps and rags. The fibers were chosen primarily to have them representative of the cellulosic purity found in the average current commercial products. The pulps and resultant papers were given extensive chemical and physical tests with particular reference to stability. In this work consideration was given to the fiber components, alpha, beta, and gamma cellulose and pentosans. The degree of retention of the initial strength and desirable chemical properties of the paper was also determined after an accelerated aging test made by heating the paper for 72 hours at 100° C.

The changes in the beta and gamma cellulose content of the heat-treated papers were not significant enough to warrant the use of these values as criteria of the stability of the papers. The present belief that alpha-cellulose content and copper number are closely related to stability of paper and that high alpha-cellulose content and low copper number, with very little change in these attributes when papers are heated, are characteristics of stable paper, is supported by

the data. Using as an index of life expectancy the chemical purity of the papers and their stability in the heat test, close relation was shown between the cellulosic purity of the pulps and the stability of the experimental unsized book papers produced from them. The stability of papers made from the same pulps when filling and sizing variables are introduced in their manufacture remains to be determined in a subsequent part of the investigation.

While the main object of the study (which is an extension of previous similar work on writing papers) is to assist paper manufacturers and users in the classification of book papers with respect to their endurance, the data should be of value to anyone interested in the preservation of valuable records. RP949 in the December number of the *Journal of Research* should be consulted for a more complete account of the work.

SIMPLIFICATION OF SIZES OF PHOTOGRAPHIC FILM FOR COPYING RECORDS.

Simplified Practice Recommendation R165–36, Photographic Film for Miniature Copies of Records, effective from August 1, 1936, is concerned with the widths of film used in copying all forms of documentary material, either as a preservation measure, or to make it more accessible. The purpose of the recommendation, which establishes 16 mm. and 35 mm. motion-picture film as the stock sizes for use in copying, is to aid in stabilizing the growth of what may be termed a new industry.

Students and others interested have found that, under conditions imposed by travel in many countries, "movie" films are readily available and easily adapted to their needs. Photographic copies so made have been variously described as "micro-copies," "film slides," "filmstats," etc.

Users state that among the advantages offered by this method of copying records are: possibility of reproducing great blocs of material at relatively low cost; ease of preservation of data; and expedition of inter-library loans.

The importance of establishing specific widths of film is evident when attention is directed to the fact that apparatus to supplement the camera itself must be designed to permit

direct reading from either the finished negative, or a film positive thereof, and to make possible satisfactory projection of the positive upon a suitable screen, or an enlargement of the recorded image upon paper as a permanent positive print.

It is believed by some workers in this field that certain types of copying cannot be accomplished adequately on areas of film that are smaller than that made possible by the 70 mm. size. However, this Simplified Practice Recommendation is concerned primarily with film that is produced for stock, in anticipation of known demand. Therefore, the use of 70 mm. film is not precluded when that size is required to fill a special need. If the 70 mm. width finds increased usage the demand will be recognized by the film manufacturers. At that time also the Simplified Practice Recommendation can be revised to bring it abreast of existing best practice.

Until the printed book is available, free mimeographed copies of the recommendation can be obtained from the Division of Simplified Practice, National Bureau of Standards, Washington, D. C.

The printed edition of the recommendation will contain, in addition to the film widths, a brief history of the project, and a list of organizations and firms which have accepted the program.

Concrete X-Ray Room Built Without Lead Lining.—(*Engineering News Record*, Vol. 117, No. 19.) Concrete instead of lead to protect laboratory operators using one of the largest industrial X-ray units in this country, is proving satisfactory at the U. S. Arsenal at Rock Island, Ill. The X-ray room with the walls, foundation and ceiling made of concrete, was designed for the use of a 400,000 volt and 10 milliampere unit. Plans for its construction called for a floor space 20 ft. square and a ceiling height of 20 ft. Had lead been used as the X-ray absorptive material, concrete walls and ceiling would have been used for supporting the lead, entailing considerably more expense. The concrete mix used was one sack of cement with 2.3 cu. ft. of sand, 3.5 cu. ft. of aggregate, and sufficient water to make a workable mix. The foundation was a 36 in. layer of concrete placed upon rock. The 24 in. walls were deposited in heights of 8 ft. because of the weight involved. A ten in. thickness of concrete forms the ceiling. When construction was completed, a survey for a period of 60 days during regular routine testing showed the walls satisfactory. In this survey dental film was placed at various points on the outside of the walls, and no darkening of this film could be detected. Two explanations are given for the X-ray absorption property of concrete: First, that the rays are widely scattered before any great penetration takes place. Second, that the scattered radiation is of longer wave-length than the initial rays and thus more easily absorbed by the remaining thickness of the material.

R. H. O.

THE FRANKLIN INSTITUTE

STATED MONTHLY MEETING, DECEMBER 16, 1936.

The regular monthly meeting of The Franklin Institute was called to order at 8:30 o'clock by the President, Mr. Nathan Hayward. He stated that the Minutes of the previous meeting had been printed in the November issue of the JOURNAL, and if there were no additions or corrections, they would stand approved as printed. There were no objections and the minutes were therefore declared approved.

The President then called upon the Secretary for a report on the state of the membership. The Secretary announced that the additions to membership since the last report were as follows: Institute members: 8 Resident, 2 Non-Resident, 9 Student. Museum members: 7 Family, 4 Individual and 24 Students—a total of 54.

The following nominations were made for officers and managers for the term beginning with January 1937:

President
(to serve one year)
Philip C. Staples

Vice-President
(to serve one year)
Henry Howson
Walton Forstall
W. Chattin Wetherill
S. S. Fels

Treasurer
(to serve one year)
Benjamin Franklin

Members of the Board of Managers
(to serve three years)
Francis T. Chambers
Irenee DuPont
W. H. Fulweiler
Nathan Hayward
Horace P. Liversidge
Malcolm Lloyd, Jr.
Marshall S. Morgan
Coleman Sellers

(to serve one year)
Clarence L. Jordan
Conrad N. Lauer

The Chairman called for other nominations, but none being presented, the nominations, on motion, were declared closed.

The Secretary then made announcement concerning the daily demonstrations in the planetarium during the present month with the exception of Christmas Day. He also called attention to the fact that an all-time record for attendance was made on Sunday, December 13—a total number of visitors to the demonstration of 2100.

Mention was also made of the James Mapes Dodge Christmas Lectures which are scheduled for the afternoons of December 28, 29 and 30. Dr. R. W. Wood of Baltimore will be the lecturer.

The Secretary called attention to the special lecture now being delivered in the lecture hall on the subject of "Flight in Nature."

The increase in attendance in the library since the summer recess was also pointed out. The telephone inquiries for technical information are numerous.

The President then introduced Dr. Ellice McDonald, Director of the Biochemical Research Foundation of the Institute, who presented a report on the work of the Foundation during the past year. This is the first year under the direction of the Institute. The Foundation existed for eight years previously as the Cancer Research Laboratories.

The speaker gave a brief résumé of some of the various phases of research work done by the Foundation, and a general description of its aims and accomplishments. He outlined the activities of each of the fifty workers and gave a general survey of the work done by them. The Foundation now occupies four floors in a modern building in West Philadelphia.

At the close of the address a brief discussion ensued. The Chairman extended the thanks of the assemblage to the speaker and the meeting adjourned.

HENRY BUTLER ALLEN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, December 9, 1936.)

HALL OF THE COMMITTEE,
PHILADELPHIA, DECEMBER 9, 1936.

MR. JOHN A. VOGLESON *in the Chair.*

The following reports were presented for first reading:

No. 3018: Proving Ring.
No. 3026 } Franklin Medal.
No. 3027 }

JOHN FRAZER,
Secretary to Committee.

THE FRANKLIN INSTITUTE.

CERTIFIED FINANCIAL STATEMENTS

for the Year ended September 30, 1936.

December 14, 1936.

To the Board of Managers of
The Franklin Institute,
Philadelphia.

We have made an examination of the balance sheet of THE FRANKLIN INSTITUTE as at September 30, 1936, and of the statements of income and expenses and general fund for the year ended that date. In connection therewith, we exam-

ined or tested accounting records of the Institute and other supporting evidence and obtained information and explanations from officers and employees of the Institute; we also made a general review of the accounting methods, of the income accounts as recorded, and of the operating and fund accounts for the period, but we did not make a detailed audit of the transactions. The real estate, buildings and equipment, and investments are stated at cost or appraised values at dates of acquisition, and do not purport to represent present day values.

Subject to the foregoing, the annexed financial statements, in our opinion, fairly present, in accordance with accepted principles of accounting consistently maintained by the Institute during the year under review, the financial position of The Franklin Institute at September 30, 1936, and the results of its operations for the year ended that date, after excluding the accounts of The Bartol Research Foundation of The Franklin Institute, and of The Biochemical Research Foundation of The Franklin Institute, on which separate reports are submitted.

LYBRAND, ROSS BROS. & MONTGOMERY.

THE FRANKLIN INSTITUTE.

BALANCE SHEET, SEPTEMBER 30, 1936.

Assets.

Cash in banks and on hand (not including cash in endowment trust funds)		$35,078.65
Accounts receivable for memberships, subscriptions, etc.		3,297.51
Materials and supplies, at cost		4,630.16
Real estate, buildings and equipment, at cost, not including exhibits loaned and donated		4,053,069.42
Deferred expenses		2,328.49
		$4,098,404.23
Endowment fund investments, cash, etc.:		
Investments, at cost or the appraised values at the dates of acquisition	$2,478,901.19	
(Investment securities of the General Endowment Fund having a value of $36,220 at market quotations as of September 30, 1936, pledged as collateral for notes payable, see contra)		
Deposit in closed bank, less reserve	85,000.00	

Cash:		
Uninvested principal	10,097.25	
Unexpended income	7,310.32	
		2,581,308.76
		$6,679,712.99

Liabilities.

Notes payable	$76,000.00
(Investment securities of the General Endowment Fund having a value of $36,220 at market quotations as of September 30, 1936, are pledged as collateral for this loan, see contra)	
Accounts payable	8,125.30
	84,125.30
Deferred income from dues, etc.	12,890.88
Contributed funds used for buildings, equipment, etc., as annexed	3,818,494.56
Stock outstanding:	
First class $13,040.00	
Second class 70.00	
	13,110.00
General Fund account, as annexed	169,783.49
	$4,098,404.23
Endowment funds:	
Principal, as annexed 2,573,998.44	
Unexpended income 7,310.32	
	2,581,308.76
	$6,679,712.99

GENERAL FUND ACCOUNT

for the year ended September 30, 1936.

Balance, October 1, 1935		$172,614.19
Add:		
Member transferred	$3.00	
First class stock surrendered and cancelled	200.00	
Amount withdrawn from the Museum Reserve Fund Principal for capital and operating expenditures	60,000.00	
		60,203.00
		232,817.19
Deduct deficit for the year ended September 30, 1936, as annexed		63,033.70
Balance, September 30, 1936		$169,783.49

INCOME AND EXPENSE ACCOUNT
for the year ended September 30, 1936.

Income.

Dues, initiation fees, etc.		$23,814.85
Less dues uncollected, prior years		1,011.50
		22,803.35
Admissions to museum and planetarium, sale of guide books, etc.		61,568.40
Subscriptions to publications and advertising		7,000.25
Donations		8,359.61
Administrative charges for services rendered The Bartol Research Foundation and The Biochemical Research Foundation		10,166.61
Miscellaneous income		906.10
		110,804.32
Income from trust fund investments, etc.		123,402.61
		$234,206.93

Expenses.

	Salaries and Wages.	Other.	
Building operation and maintenance	$35,008.12	$29,862.57	
Library	14,426.97	5,842.80	
Meetings	—	2,785.35	
Office and general	52,661.76	11,234.64	
Machine shop	396.66	394.00	
Museum	75,969.74	37,755.06	
Publications	—	13,626.23	
Science and The Arts	4,143.92	245.15	
Traveling expense	—	823.19	
Membership drive	—	3,532.39	
Annuities	4,875.02	—	
Interest and discount	—	3,420.33	
Membership badges and certificates	—	236.73	
	$187,482.19	$109,758.44	
			297,240.63
Deficit for the year			$63,033.70

SUMMARY OF CHANGES IN ENDOWMENT FUNDS
for the year ended September 30, 1936.

Balances, October 1, 1935		$2,700,306.26
Add:		
Profit on sale of investments	$8,556.75	
Amounts received for life memberships	800.00	
Miscellaneous	7.62	
		9,364.37
		$2,709,670.63

Deduct:		
Losses on sale of investments	69,472.83	
Amount withdrawn from the Museum Reserve Fund for capital and operating expenditures, credited to General Fund Account	60,000.00	
Amount received as a distribution from principal of the John G. Meigs Bequest, credited to John G. Meigs Memorial Fund (income account)	6,199.36	
		135,672.19
Balances, September 30, 1936		$2,573,998.44

CONTRIBUTED FUNDS RECEIVED FROM BENJAMIN FRANKLIN MEMORIAL, INC.,
for the year ended September 30, 1936.

Balance, October 1, 1935	$3,816,744.71
Add pledges collected, net of expenses of collection	1,749.85
Balance, September 30, 1936	$3,818,494.56

THE BARTOL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE

CERTIFIED FINANCIAL STATEMENTS

for the Year ended September 30, 1936.

December 14, 1936.

To the Board of Directors of
The Franklin Institute,
Philadelphia.

We have made an examination of the balance sheet of THE BARTOL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE as at September 30, 1936, and of the statement of income and expenses for the year ended that date. In connection therewith, we examined or tested accounting records of the Foundation and other supporting evidence and obtained information and explanations from officers and employees of The Franklin Institute; we also made a general review of the operating and fund accounts for the period, but we did not make a detailed audit of the transactions. The building,

which is located on the property of Swarthmore College, and the equipment are stated at cost and the investments at cost or appraisal values at dates of acquisition and do not purport to represent present day values. The cost of books and scientific literature is charged to expense.

Subject to the foregoing, the accompanying balance sheet and related statement of income and expenses, in our opinion fairly present, in accordance with accepted principles of accounting consistently maintained by the Foundation during the year under review, its financial position at September 30, 1936, and the results of its operations for the year ended that date.

LYBRAND, ROSS BROS. & MONTGOMERY.

THE BARTOL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE.

BALANCE SHEET, SEPTEMBER 30, 1936.

Assets.

Cash:			
In bank and on hand, general fund		$492.77	
Unexpended income:			
Henry W. Bartol Bequest	$12,246.81		
Investment of unexpended income fund	7,836.00	20,082.81	
			$20,575.58
Accounts receivable, employees			34.79
Investments of unexpended income fund, at cost			200,868.54
Building and equipment, at cost:			
Laboratory building		226,591.05	
Furniture and fixtures		14,874.93	
Equipment:			
Laboratory	$82,035.05		
Less allowance for depreciation	14,574.73	67,460.32	
Machine shop	16,831.75		
Less allowance for depreciation	2,168.51	14,663.24	
Office		2,953.47	
Library		1,057.65	
			327,600.66
			$549,079.57

Investments (at cost or appraised values at dates of acquisition) and cash of principal of trust funds:

	Investments.	Cash.	
Henry W. Bartol Bequest	$1,308,159.81	$12,255.39	
Pension fund	63,963.36	5,928.66	
	$1,372,123.17	$18,184.05	
			1,390,307.22
			$1,939,386.79

Collateral Trusts.

Cash:			
Uninvested principal	$1,630.78		
Undistributed income	2,195.98	$3,826.76	
Investments:			
Helene Bonar Bartol Trust	306,891.49		
Lucy Cheyney Farr Trust	153,090.91		
Katherine de Monclos Trust	152,627.97	612,610.37	
			616,437.13
			$2,555,823.92

Liabilities.

Accounts payable			$2,308.35
General Fund account:			
Balance, October 1, 1935		$537,443.53	
Excess of income over expenses for the year ended September 30, 1936, as annexed		9,327.69	
			546,771.22
			$549,079.57
Endowment Funds:			
Henry W. Bartol Bequest		1,320,415.20	
Pension fund		69,892.02	
			1,390,307.22
			$1,939,386.79

Collateral Trusts.

Principal:			
Helene Bonar Bartol Trust	$307,491.18		
Lucy Cheyney Farr Trust	153,477.48		
Katherine de Monclos Trust	153,272.49		
		614,241.15	
Undistributed income		2,195.98	
			616,437.13
			$2,555,823.92

INCOME AND EXPENSE ACCOUNT
for the year ended September 30, 1936.

Income.

Income received from investments	$62,827.85
Other income:	
Contribution from American Philosophical Society for salaries of research professors	750.00
	$63,577.85

Expenses.

	Salaries and Wages.	Other.	
Building operation and maintenance	$1,045.32	$3,237.22	
Library	—	849.95	
Administrative and general	14,121.52	2,078.52	
Laboratory and machine shop	23,729.98	2,643.24*	
Publications, reprints	—	386.92	
Traveling expense	—	157.49	
Administrative charge, The Franklin Institute	—	6,000.00	
	$38,896.82	$15,353.34	
			$54,250.16
Excess of income over expenses for the year, transferred to General Fund Account			$9,327.69

* Includes provision of $949.20 for depreciation of laboratory equipment.

THE BIOCHEMICAL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE

CERTIFIED FINANCIAL STATEMENTS

as at August 31, 1936.

December 14, 1936.

To the Board of Managers of
The Franklin Institute,
Philadelphia.

We have made an examination of the balance sheet of THE BIOCHEMICAL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE as at August 31, 1936, and of the statement of expenses and income for the period from July 1, 1935, to August 31, 1936. In connection therewith, we examined or tested the accounting records of the Foundation and other

supporting evidence and obtained information and explanations from officers and employees of The Franklin Institute; we also made a general review of the accounting methods and of the operating and fund accounts for the period, but we did not make a detailed audit of the transactions. The research apparatus and other equipment are stated at their appraised values on July 1, 1935, with additions since that date at cost; the investments are stated at appraised values at dates of acquisition.

Subject to the foregoing, the accompanying balance sheet and the related statement of expenses and income, in our opinion, fairly present, in accordance with accepted principles of accounting consistently maintained by the Foundation during the period under review, its financial position at August 31, 1936, and the results of its operations for the period from July 1, 1935, to August 31, 1936.

LYBRAND, ROSS BROS. & MONTGOMERY.

THE BIOCHEMICAL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE.

BALANCE SHEET, AUGUST 31, 1936.

Assets.

Cash:		
In general checking account and on hand		$7,908.59
Unexpended cash of funds available for current operations:		
Biochemical Research Foundation	$104,320.62	
Emma M. Schaible Bequest	829.29	105,149.91
Unexpended cash of funds available for bonuses to employees (see contra)		6,389.45
		$119,447.95
Investments, at appraised values at dates of acquisition:		
Biochemical Research Foundation		183,500.00
Emma M. Schaible Bequest		1,760.50
		185,260.50
Equipment, at appraised value July 1, 1935, with subsequent additions at cost:		
Research apparatus and equipment		127,420.91
Improvements to leased equipment		3,548.83
Cyclotron experiment		3,632.68
Library books		1,503.26
		136,105.68

200 shares Hendry-Connell Research Foundation, Ltd., par value $100, at nominal value		2.00
Deferred charges, amounts due under agreement (see contra)		50,000.00
		$490,816.13

Liabilities.

Accounts payable		$1,937.24
Amount due Hendry-Connell Research Foundation, Ltd., pledged for the year ending August 31, 1937, under terms of agreement dated December 6, 1935 (see contra)		25,000.00
		26,937.24
Amount due Hendry-Connell Research Foundation, Ltd., pledged for the year ending August 31, 1938, under terms of agreement dated December 6, 1935 (see contra)		25,000.00
Unexpended income of funds, available for bonuses to employees (see contra)		6,389.45
General Fund account:		
Balance, July 1, 1935	$570,779.31	
Add nominal value assigned to shares of Hendry-Connell Research Foundation, Ltd.	2.00	
	570,781.31	
Less excess of expenses over income available for purposes of the Foundation, for the period from July 1, 1935, to August 31, 1936, as annexed	138,291.87	
		432,489.44
		$490,816.13

STATEMENT OF EXPENSES AND INCOME

for the period from July 1, 1935, to August 31, 1936.

Expenses.

	Salaries and Wages.	Other.	
Building operation and maintenance	—	$10,437.21	
Administrative and general	$32,621.20	3,022.78	
Laboratory	73,597.47	11,516.73	
Publications and printing	—	578.43	
Dues and subscriptions	—	863.52	
Traveling and entertainment	—	2,445.52	
Administrative charge, The Franklin Institute	—	3,749.95	
Miscellaneous	—	502.07	
	$106,218.67	$33,116.21	
			$139,334.88

Advance to the Hendry-Connell Research Foundation, Ltd., under agreement dated December 6, 1935		25,000.00
		$164,334.88

Income.

Income received from investments	$113.21	
Other income:		
Profit on sale of investments	25,929.80	
		26,043.01
Excess of expenses over income for the period, transferred to General Fund account		$138,291.87

LIBRARY NOTES.

RECENT ADDITIONS.

Biography.

BISHOP, MORRIS. Pascal. The Life of Genius. 1936.

Chemistry and Chemical Technology.

BONE, WILLIAM A., AND GODFREY W. HIMUS. Coal. Its Constitution and Uses. 1936.

BRUNCK, OTTO. Quantitative Analyse. 1936.

Faraday Society. Phenomena of Polymerisation and Condensation. A General Discussion. No date.

JEBSEN-MARWEDEL, HANS. Glastechnische Fabrikationsfehler. 1936.

KELLY, FRED C. One Thing Leads to Another. 1936.

MERRY, E. W. The Chrome Tanning Process. First Edition. 1936.

POUCHER, WILLIAM A. Perfumes, Cosmetics and Soaps with Especial Reference to Synthetics. Three volumes. 1936.

ROWELL, HERBERT W. The Technology of Plastics. 1936.

SUCHARDA, EDUARD, AND BOGUSLAW BOBRANSKI. Semimicro-Methods for the Elementary Analysis of Organic Compounds. Authorized Translation by George W. Ferguson. No date.

Electricity and Electrical Engineering.

ARDENNE, MANFRED VON. Television Reception. Translated by O. S. Puckle. 1936.

ECKHARDT, GEORGE H. Electronic Television. 1936.

MYERS, L. M. Television Optics. 1936.

PALMER, L. S. Wireless Engineering. 1936.

PENDER, HAROLD, AND OTHERS. Electrical Engineers' Handbook. Two volumes. 1936.

ROBINSON, D. M. Dielectric Phenomena in High Voltage Cables. 1936.

Geology.

MACELWANE, J. B., AND F. W. SOHON. Introduction to Theoretical Seismology. Part 1: Geodynamics. 1936.

Mathematics.

COURANT, R. Differential and Integral Calculus. Translated by E. F. McShane and J. E. McShane. Two volumes. 1934–1936.

DAVENPORT, C. B., AND MERLE P. EKAS. Statistical Methods in Biology, Medicine and Psychology. Fourth, completely revised, Edition. 1936.

DRESDEN, ARNOLD. An Invitation to Mathematics. 1936.

Mechanical Engineering.

JUDGE, ARTHUR W. Maintenance of High Speed Diesel Engines. 1936.

KENT, WILLIAM. Kent's Mechanical Engineers' Handbook. Eleventh Edition, Rewritten by Robert Thurston Kent. 1936.

MACGIBBON, WM. C. Indicator Diagrams, Steam and Oil, for Marine Engineers. Fifth Edition. No date.

STANIAR, WILLIAM. Mechanical Power Transmission Handbook. First Edition. 1936.

Metallurgy and Metalwork.

EVANS, T. FRANKLIN. Hammered Metalwork. 1936.

ZEERLEDER, ALFRED VON. The Technology of Aluminium and its Light Alloys. Translated from the 2nd German Edition into English by A. J. Field. 1936.

Naval Architecture and Navigation.

LUBBOCK, BASIL. The Opium Clippers. 1933.

Photography.

DALZELL, J. MOIR. Practical Stereoscopic Photography. 1936.

DESCHIN, JACOB. New Ways in Photography. 1936.

Physics.

BAYLEY, PAUL LAVERNE, AND CHARLES CLARENCE BIDWELL. An Advanced Course in General College Physics. 1936.

EWALD, P. P., TH. PÖSCHL, AND L. PRANDTL. The Physics of Solids and Fluids with Recent Developments. Authorized Translation by J. Dougall and W. M. Deans. Second Edition. 1936.

International Printing Ink Corporation. Research Laboratories. A Series of Monographs on Color. Three volumes. 1935.

KEENAN, JOSEPH H., AND FREDERICK G. KEYES. Thermodynamic Properties of Steam Including Data for the Liquid and Solid Phases. 1936.

LONSDALE, KATHLEEN. Simplified Structure Factor and Electron Density Formulae for the 230 Space Groups of Mathematical Crystallography. 1936.

Munsell Book of Color. 1929.

Scientific Essays.

GARBEDIAN, H. GORDON. The March of Science. A Popular Introduction to the Story of the Universe and Man's Place on Earth. 1936.

Sugar.

Louisiana Sugar Manual. 1936–37. Twenty-sixth Annual Edition. 1936.

Water Supply.

LEHR, G. J. Das Trink- und Gebrauchswasser: seine Gewinnung, Aufbereitung und Verteilung. 1936.

BOOK REVIEWS.

A SURVEY COURSE IN PHYSICS, by Carl F. Eyring, PhD. 378 pages, illustrations, tables, 16 × 24 cms. New York, Prentice-Hall, Inc., 1936. Price $3.00.

This is an unusual book for an unusual purpose. It is designed especially for non-science students and serves as an orientation course. To achieve this aim, the author does not present a book on a short course in physics, skimming over the field, but he presents a book written specifically from the viewpoint of the needs, capabilities, and inclinations of such students. It is the result of a trial course started several years ago and through experience has proved successful.

From the very beginning, sympathy with the needs and desires of the student is shown, and interest is created by the very straightforward indications of this and sound logical explanations of the interpretations of immediate physical environment. For instance, in Chapter Two on Size, Weight and Balance, the subject is treated from personal manifestations of it. In introducing this chapter the reader is reminded of his own experience with everyday objects such as stones, trees, furniture and even persons with relation to size, weight and shape. This sort of individual touch and simplicity is carried throughout the book.

Another outstanding feature is the diversity of topics covered. They include explanations of the atom, physics of the household, vibrations and waves, sound and musical instruments, color, optical instruments, and the generation of electricity. The subjects covered are limited, the personal choice of the author, but their diversity is sufficient for the purpose. Emphasis can be placed on certain parts of the book in accordance with the type or class of student. Necessarily, there is very little mathematics used or required in this book. Its omission brought a serious challenge in presenting the subject clearly. The author has not only met this squarely but has succeeded in making this book interesting for those for whom it is intended.

The illustrations are noteworthy in that they follow the underlying idea of the author and assist greatly in making the subject matter impressive. A useful subject index completes the book.

Everyone reading this book whose training and experience has been other than technical should place himself in the classification of the student for whom it is originally intended. It is enlightening, interesting, easy to read and will make a valuable addition to general knowledge.

R. H. OPPERMANN.

KENT'S MECHANICAL ENGINEERS' HANDBOOK. Vol. II, Power, by Robert Thurston Kent. Price $5.00. ELECTRICAL ENGINEERS' HANDBOOK. Vol. IV, Electric Power, edited by Harold Pender, William A. Del Mar, and Knox McIlwain. Price $6.00. Volume V, Electric Communication and Electronics, edited by Harold Pender and Knox McIlwain. Price $5.00. 3 volumes, variously paged, 14.5 × 22 cms. New York, John Wiley & Sons, Inc. London, Chapman & Hall, Ltd., 1936.

In the November 1936 number of the JOURNAL OF THE FRANKLIN INSTITUTE there appeared on page 641 a review of the Handbook of Engineering Fundamentals. This was the first of a series of handbooks under a new arrangement of John Wiley and Sons, Inc., the publishers. The motivating idea of this series was to

avoid the bulkiness and inconvenience occasioned by the new material that would have to be added to new editions of handbooks.

The books at hand conform with this new arrangement. Kent's Mechanical Engineers' Handbook is the eleventh edition, the tenth being the 1923 edition. It is volume two of the new series and represents a complete rewriting of the book although the principle that has governed the ten previous editions has constantly been followed—namely that it represent the practice of mechanical engineering. There will be two volumes of "Kents," this one devoted to power and the succeeding volume which is now in press will be devoted to design and shop practice. There are seventeen sections to the power volume each on a particular subject. Section topics include air, water, heat, steam boiler, steam engine, steam turbine, refrigeration, internal combustion engines, gas producers, etc.

Pender's Handbook for Electrical Engineers has been well known and much used in this profession. Rapid developments since the last edition fourteen years ago has made it necessary to revise the book. Here is the revision. Volume four of the series edited by Harold Pender, W. A. Del Mar and K. McIlwain is devoted entirely to electric power production and utilization. Volume five of the series edited by Pender and McIlwain covers electrical communication and electronics. Electrical engineers will recognize the value in separating these two main divisions of their subject.

Sufficient duplication of such general engineering topics as tables and fundamental theories is contained in each volume, to make it independent of the other. In addition, this handbook series makes it possible to give far more effective treatment to every individual sub-topic.

R. H. OPPERMANN.

TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS, Vol. 120, Iron and Steel Division, 1936. 411 pages, tables, illustrations, 16 × 23.5 cms. New York, Institute, 1936.

This volume is the ninth of a series containing papers and discussions presented before the Iron and Steel Division of the American Institute of Mining and Metallurgical Engineers. Its contents cover the subjects of corrosion of steel and high-tensile low-alloy steel, ore preparation and blast furnace problems, physical metallurgy and devices for measurement of temperature. Professor Moore's Howe Memorial Lecture on "Correlation Between Metallography and Mechanical Testing" is an outstanding work and should be studied by all metallurgists.

These papers and discussions were presented at the meetings at Chicago, October 1–3, 1935, and New York, February 17–21, 1936.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

Cyanidation and Concentration of Gold and Silver Ores, by John V. N. Dorr. 485 pages, tables, illustrations, 15.5 × 23.5 cms. New York and London, McGraw-Hill Book Company, Inc., 1936. Price $5.00.

Prelude to Chemistry, An Outline of Alchemy, Its Literature and Relationships, by John Read. 328 pages, plates, 16 × 24 cms. New York, The Macmillan Company, 1937. Price $5.00.

The Mechanical Testing of Metals and Alloys, The Theory and Practice of

Standardized Mechanical Testing, by P. Field Foster. 267 pages, tables, illustrations. 14 × 22 cms. New York, Pitman Publishing Corporation, 1936. Price $3.75.

Preparation of Scientific and Technical Papers, by Sam F. Trelease and Emma Sarepta Yule. 125 pages, tables, 13 × 19 cms. Baltimore, The Williams and Wilkins Company, 1936. Price $1.50.

An Introduction to Nuclear Physics, by N. Feather. 213 pages, tables, illustrations, 14.5 × 22.5 cms. Cambridge, University Press, 1936. Price $3.00.

Thermodynamic Theory of Affinity, a Book of Principles, by Th. de Donder and Pierre Van Rysselberghe. 141 pages, 16 × 24.5 cms. Stanford University, Stanford University Press, 1936. Price $3.00.

Kernphysik Vorträge Gehalten am Physikalischen Institut der Eidgenössischen Technischen Hochschule Zürich im Sommer 1936 (30. Juni–4. Juli), herausgegeben von Dr. E. Bretscher. 141 pages, tables, diagrams, 16 × 24.5 cms. Berlin, Julius Springer, 1936. Price 12 marks.

Relativity Theory of Protons and Electrons, by Sir Arthur Eddington. 336 pages, 18 × 27 cms. New York, The Macmillan Company; Cambridge, England, University Press, 1936. Price $5.50.

Thermodynamic Properties of Steam, including Data for the Liquid and Solid Phases, by Joseph H. Keenan and Frederick G. Keyes. 89 pages, 19.5 × 26 cms. New York, John Wiley & Sons, Inc.; London, Chapman & Hall, Ltd., 1936. Price $2.75.

Jones Antenna Handbook, by Frank C. Jones. 64 pages, illustrations, tables, 15 × 23 cms. San Francisco, Author, 1937. Price fifty cents.

Presentation of the Bust of Lord Kelvin to the Smithsonian Institution by the English-Speaking Union. 40 pages, plates, 14 × 20 cms. Washington, English-Speaking Union, 1936.

National Bureau of Standards, Circular C412, Silver: Its Properties and Industrial Uses, by B. A. Rogers, Irl C. Schoonover, and Louis Jordan. 72 pages, tables, 15 × 23.5 cms. Washington, Government Printing Office, 1936. Price ten cents.

U. S. Department of Agriculture, Report of the Secretary of Agriculture, 1936. 115 pages, 15 × 23 cms. Washington, Government Printing Office, 1936.

A Yearbook of Railroad Information, 1936 edition. 96 pages, illustrations, 10 × 15.5 cms. New York, Committee on Public Relations of the Eastern Railroads, 1936.

Bell Telephone Laboratories. Monographs: B-954, Modified Sommerfeld's Integral and Its Applications, by S. A. Schelkunoff, 11 pages. B-955, The Corrosion of Metals—II, by R. M. Burns, 23 pages. B-957, Microchemical and Special Methods of Analysis, by Beverly L. Clarke and H. W. Hermance, 21 pages. B-962, Some Data on a Room Designed for Free Field Measurements, by E. H. Bedell, 8 pages. 4 pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1936.

National Advisory Committee for Aeronautics, Technical Notes. No. 584, Effect of Several Factors on the Cooling of a Radial Engine in Flight, by Oscar W. Schey and Benjamin Pinkel, 11 pages, illustrations. No. 585, Mechanical Properties of Aluminum-Alloy Rivets, by Wm. C. Brueggeman, 11 pages, illustrations. No. 586, The Reduction of Aileron Operating Force by Differential Linkage, by Robert T. Jones and Albert I. Nerken, 13 pages, illustrations. 3 pamphlets, 20 × 26 cms. Washington, Committee, 1936.

CURRENT TOPICS.

Out of Rugs.—(*General Electric Review*, Vol. 39, No. 10.) A device which locates broken needles in rugs and carpets has recently been developed by the General Electric Co. In spite of the precautions taken, the needles used in the manufacture of rugs and carpets may break and become deeply imbedded in the finished product. The new equipment will be used to replace former tedious and time-wasting methods of inspection. With it, the presence and exact location of the steel barb can be ascertained by passing the rug or carpet through a frame twice in directions at right angles. The device consists of a test coil, a motor generator set, and an amplifier. Power is supplied by the motor generator set at 2160 cycles to the test coil which has two primary and two secondary windings. The secondary windings of the test coil are connected differentially, or opposed. The secondary circuit is balanced before an inspection run. The carpet or rug passes through a narrow slit, going through first one set of primary and secondary windings and then the other. The passage of broken needle causes a distortion in the magnetic field and produces an unbalanced voltage in the secondary circuit. This unbalance is amplified by the resistance coupled amplifier in the secondary circuit and causes a relay to open and signal lights to operate. Lengthwise and transverse passes of the rug or carpet are all that are necessary to detect the needle along two lines which intersect and give the exact location of the imbedded needle.

R. H. O.

Concrete Treated by Vacuum Compression.—(*Construction Methods*, Nov. 1936.) Vacuum compression for treating freshly poured concrete road slab to remove excess water and compact and strengthen the mix in place was demonstrated on the northerly traffic lane of the Manhattan approach span of the Queensboro Bridge, New York City. The process was developed by the Vacuum Concrete Corporation. Upon the wet concrete surface are placed, one alongside the other, three 3 × 10 ft. wood frames or vacuum units, each covered on top with an airtight sheet of No. 18 gage galvanized iron and on the bottom by a tightly stretched sheet of canvas treated with a copper solution to harden its fibers. Between these top and bottom covers is sandwiched a separating mat of expanded

metal which forms a compartment ⅛ in. thick, to which suction is applied through a 1 in. hole in the galvanized metal cover by a hose line from a vacuum pump on a motor truck. Underneath the canvas bottom of each frame is a grid in the form of a punched metal plate ⅛ in. thick, with 2½ in. square openings, whose function is to score the concrete surface an anti-skidding measure. By means of handles at the ends, the three frames are firmly bedded alongside of each other upon the soft concrete surface of the slab. Then rubber cups on the ends of the vacuum hose line are placed over the 1 in. openings in the galvanized iron sheets forming the top covers of the frames. The suction thus created by a vacuum of 23 to 26 in. of mercury above the top surface of the concrete performs two functions: It removes excess water from the concrete mix and at the same time enables atmospheric pressure, acting on the top surface of each frame, to bear down upon the concrete, compacting and consolidating it. The vacuum is applied for a period of about 5 min., when the frames are raised and transferred to a new strip of slab.

R. H. O.

Bucket-Spinning Motors.—H. D. ELSE. (*The Electric Journal*, Vol. 33, No. 11.) The job demanded of a motor to spin a bucket in the process of rayon manufacture is prodigious. It must be capable of operating at a speed of about 8000 r.p.m. continuously with an unbalanced load in an atmosphere laden with moisture and acid fumes. Additional burdens are imposed on it by its location—directly beneath the bucket, where it is exposed to drip; and by the fact that it may be required to start and stop, in an unusual case as often as 40 times an hour. It is subjected to further shocks by the bucket being taken off the spindle occasionally and dropped back into place. Such an application, in its required total revolutions has no parallel in any industry. Speed and adverse operating conditions preclude the possibility of using gears or tape; and a special totally enclosed, low voltage, high-frequency, polyphase, squirrel-cage motor is the accepted modern drive. Speeds higher than the present 8000 r.p.m. are contemplated, and motors are tested commercially at 10,000 r.p.m. Although the buckets are carefully balanced, a total unbalance of from 5 to 10 grams at a ½ in. radius can be anticipated within a few months. If conventional methods were used to withstand the resulting stress—about 300 lbs.—the housing and supports would have to be massive. In recent types of the spinning motor, however, the shaft has been made long and slender, the motor housing relatively light, and internal damping means employed. Concentric sleeves, submerged in oil, surround the lower end of the

bearing tube. Small clearances between sleeves permit movement of the oil when the motor is passing through critical speeds, which are deliberately made low—at about 500 r.p.m. Careful attention was given the matter of lubrication in which an ingenious limited feeding arrangement was adopted.

R. H. O.

Will Try to Disintegrate the Atom with Electrostatic Generator. —(*Electrical World*, Vol. 106, No. 47.) To gain information as to the production and control of high voltages, of increasing importance in the field of nuclear transmutations, the Westinghouse Electric and Manufacturing Company is building, at its research laboratories in East Pittsburgh, an electrostatic generator designed to reach d.c. potentials of 5,000,000 volts or more. A large high-pressure vessel, shaped somewhat like an incandescent light bulb, will be used to secure the high voltages. The vessel, mounted on the roof of a two story laboratory building, is 47 ft. high; the upper, hemispherical part has a diameter of 30 ft. In the center of the upper end of the tank will be mounted a 15 ft. spherical electrode, with which it will be possible to maintain steady potentials using air under pressures up to 120 lb. per square inch. The voltages will be reached by using charged rubber belts in the modernized Van der Graaf version of an electrostatic machine. The electrode is supported by four large micarta insulating columns and connected to the lower ground end of the vessel by means of a segmented porcelain vacuum tube which contains the lens electrodes to focus the nuclear projectiles onto the desired targets. These nuclear projectiles—protons, deuterons and alpha particles—are formed at the high potential electrode and finally focused onto a small target spot about 35 ft. away from the point of formation of the bombarding ions. It is believed by the scientists who plan to use this apparatus, that the steady nuclear beams of homogeneous energy, necessary in these investigations in nuclear physics, are most readily attainable through the projected design of high voltage equipment.

R. H. O.

Steamotive.—E. G. BAILEY, A. R. SMITH, AND P. S. DICKEY. (*Mechanical Engineering*, Vol. 58, No. 12.) Studies made some few years ago indicated that there should be a good field of application for small steam generating units of good efficiency, relatively light weight, and small space requirements, in the field of power generating equipment for installations of from about 1000 hp. to 10,000 hp. In order to compete with other prime movers in this field the steam should be generated at as high pressure and temperature as appears

feasible; and in order to reduce the operating expense is was agreed that fully automatic control of the steam generation in response to changes in demand would be a very desirable feature. After considering this problem the General Electric Co., The Babcock & Wilcox Co., and Bailey Meter Co., completed a unit called "Steamotive." It was oil-fired and designed for an output of 21,000 lb. of steam per hr. at a pressure of 1500 lb. and a temperature of 1050 F. leaving the superheater, later changed to 900 F. These specifications conformed to the requirements of a steam-turbine-electric locomotive. This unit is now in commercial service at the Lynn Works of G. E. Another has been built for a large industrial concern and orders have been received for two each of 40,000 lb. per hr. capacity for the Union Pacific Railroad for driving two 2500 hp. locomotives. Special features of the Steamotive include small space required and flexibility in adapting boiler to limits in height, width or length; minimum weight; high convection transfer rates; elimination of refractory in furnace and boiler setting, replaced by water walls and insulating block; quick starting from a cold condition, requiring less than 10 minutes; combustion liberation rates up to 400,000 B.T.U. per cu. ft. per hr.; complete automatic control thoroughly practical; smokeless combustion.

R. H. O.

"Old Ironsides" Gets New Air Conditioning System.—(*Refrigerating Engineering*, Vol. 32, No. 6.) As part of the precautions now being taken to preserve the gun deck and berth deck of the U. S. Frigate "Constitution," Carrier air conditioning has just been installed. Modern science is now contributing to the prevention of shrinking and checking the timbers of these two decks. Many of the original timbers in "Old Ironsides" deteriorated thus necessitating their renewal. Search for the desired replacement wood of proper quality and seasoning required many years. During the winter the gun and berth decks are heated for the comfort of the thousands of visitors to this oldest ship in the U. S. Navy. Installation of a simple heating system would reduce the air's relative humidity and therefore tend to dry out excessively the timbers and result in abnormal shrinkage and checkage.

R. H. O.

1.4 Years Are Added to Life of Car.—(*National Petroleum News*, Vol. XXVIII, No. 47.) The average passenger car life today was estimated to be 8.4 years as against an older estimate of 7.04 years, by Marcus Ainsworth and A. L. Clayden at the annual

meeting of the American Petroleum Institute from an analysis of passenger automobile registrations.

R. H. O.

Heating 10,000 Hens.—(*Heating, Piping and Air Conditioning*, Vol. 8, No. 12.) Ten thousand hens laying eggs—not on a country poultry farm but in a six-story reinforced concrete factory in Chicago's industrial district. This is the achievement of a modern business enterprise which has proved the salvation of a "white elephant" real estate investment. The building was originally designed and erected as a warehouse and service building. In it each hen is provided with its private cage—clean, sanitary, well lighted, properly ventilated and heated. Food is supplied in scientifically correct amount and quality and the hens respond by maintaining an egg laying rate exceeding the normal. A great amount of mechanical apparatus is needed. The cages are stacked in tiers four high, in rows ten long. There are facilities for removing the manure, which becomes valuable fertilizer. The cage floors slope into a rack outside the cage; the egg rolls into this rack to be picked at the next collection, at which time the weight of the egg will be entered on the chicken's individual chart. The eggs must be sorted by weight, put in cartons, and crated. Food must be stored, mixed and distributed to the birds. But of all the apparatus and equipment required, none involved greater uncertainty in original design than the heating and ventilating. Poultrymen know how to feed and tend laying hens, but neither the poultrymen nor heating men know much about heating hens. To solve this problem it was necessary to provide four different temperatures in as many parts of the building, to regulate the humidity in one part, and to remove odors from the entire building. Special attention had to be given to the control of fans and burners in order that their arrangement was such as to prevent their bucking each other with consequent waste of fuel.

R. H. O.

Railway Equipment of the Future.—MR. W. A. NEWMAN, Chief Mechanical Engineer of the Canadian Pacific Railway, recently stated before the Toronto Railway Club that the possibility of automotive and air competitors surpassing the railways in stature seems remote. From the Canadian standpoint he analyzes the airplane, passenger car, bus and truck as competitors, coming to the conclusion that together they represent a formidable problem for the railroads. The analysis points to the conclusion that railways must modernize, in some respects, similar to these com-

petitors. Modern railway cars are too heavy, built for abuse and not use. Stronger alloy and stainless steels and aluminum are partial answers. Train speeds must increase, including freight trains. For both freight and passenger service lighter weight and better cars means cheaper investment. Locomotion also will be given attention. Seven per cent. of the potential power in coal is all that is converted into useful work in the steam locomotive. Electric traction, many forms of steam locomotives, and the Diesel engine have been projected to supplant the present steam locomotive. The latter is coming much into the limelight. Whether the light train and locomotive trend will continue to match the Diesel development is debatable If they do not, there is no reason why the steam locomotive should not change its form and performance. If steam power does change, the specification requirements will probably have to be, (1) better application of power over the entire speed range, (2) quicker acceleration, (3) reduced variation in the steam rate, (4) reduced variation in the boiler efficiency. There is no reason why all these improvements should not be secured.

R. H. O.

Paper Insulation.—Engineering Foundation, with the sponsorship of American Institute of Electrical Engineers, has appropriated $5,000 for an experimental research on the "Stability of Impregnated Paper Insulation." The work is to be done in the School of Engineering of The Johns Hopkins University under the direction of Dr. J. B. Whitehead, Professor of Electrical Engineering. It is expected that the present program will be extended through a second year.